The HUMAN and its Functions: an Elementary Text-book of Physiology

REVISED EDITION

NEW YORK

BODY

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To

M. M. B. and I. B. T.

PREFACE

This edition has been largely rewritten and expanded by the inclusion of much new material; many illustrations have also been added and a number of old ones redrawn. Since the first edition was published, outstanding discoveries have been made which have led to important and rapid developments in the fields of physiology and the allied branches of science. These advances have been incorporated except where the general background of knowledge required for their understanding is greater than can possibly be given in a book of this scope. The subject with respect to both style of presentation and factual matter has been treated at a rather less elementary level than in the previous edition. Also, on certain items of interest a little beyond the aim of the general text more detailed information has been given in footnotes or the legends of figures.

N. B. T.

Toronto
March 15, 1948

From the Preface to the First Edition

Physiology comprises the study of the actions or functions of the various tissues and organs of the body, but before the function of any organ can be studied and understood, one must possess some knowledge of its structure. Its general plan as seen by the naked eye, as well as its microscopical appearance, is usually essential in order to gain an insight into the way in which the tasks of any organ are performed. Often a knowledge of structure alone carries one a long way toward the understanding of function; this is espe-

cially so in the study of the central nervous system. Some acquaintance with chemistry and physics is also necessary in order to grasp the fundamental principles of many physiological processes. The study of bodily function may be said, therefore, to rest upon a tripod of sciences—anatomy, chemistry, and physics. It has been realized that many of those for whom the book has been planned will perhaps have little knowledge of these subjects. Consequently, where the principles of one or the other of these sciences are involved in the description of a physiological process, some space has been devoted to their explanation. This has, however, always been restricted to the essential needs of the particular physiological problem under discussion.

There is much in the study of human physiology which should prove of value and interest to persons entering callings other than those in which a technical knowledge of the subject is essential. Physiology should not be valued solely as a technical study, but should be looked upon rather as a desirable addition to any student's general knowledge, whatever the career for which he is being prepared. Today the layman cannot consider himself well informed and remain ignorant of some of the more recent advances in physiological science. Vitamins, proteins, calories, insulin, thyroid, pituitary, etc., are words seen daily in print, yet they have little real meaning for many of those who read them, since the scientific knowledge for which these words are no more than labels is lacking.

In the belief that by simplicity of expression a scientific fact is clarified and gains rather than loses force, an endeavor has been made to present the material in as simple language as possible. A technical term has not been used where a plain simple word and one with which the reader is more likely to be familiar would express the meaning. The style may at times appear to some readers to be too colloquial, but no apology is offered for this, provided that the meaning is clear. Where it has been necessary to employ scientific terms these have been explained at the time that they were first mentioned. A pronouncing glossary has been placed at the end of the text.

Toronto C. H. B.
October 1932 N. B. T.

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chapter 1

ATOMS AND MOLECULES

The atom.—All matter, living or non-living, is made up of inconceivably small particles called *atoms*. Atoms may therefore be looked upon as the building material from which everything we see, feel, touch, and taste is made. Atoms make up the air we breathe and our food and water.

Atoms are of different types; an atom of iron, for instance, is different in size and in weight from an atom of gold, and a gold atom is different again from one of silver, of copper, or of carbon. Materials which are each composed entirely of one type of atom, such as iron, gold, calcium, phosphorus, sodium, carbon, oxygen, etc., are called *elements*.

The atom itself is made up of minute particles or units of electricity—*protons, electrons,* and *neutrons*. Protons are units of positive electricity, whereas electrons are units of negative electricity. Neutrons are electrically neutral. The electrons are believed to revolve at high speed in concentric circles or orbits around a central core or *nucleus* composed of protons and neutrons (Fig. 1.1). A pair each of protons and neutrons are grouped together to form units known as *alpha particles,* which are shot out at high velocity from radioactive atoms.

The atom may be compared to a miniature solar system, the electrons representing the planets and the nucleus the sun. If the atom could be enlarged until its nucleus was the size of a basketball, the electrons would be the size of golf balls whirling around the nucleus at high speed and separated from it by a distance of several feet.

The properties of any particular type of atom depend upon the number of protons in its nucleus. An atom of iron, for example,

possesses more protons than an atom of oxygen or carbon or calcium but fewer than an atom of copper or zinc. One proton more or less in an atom is sufficient completely to alter its character and the properties of the mass of substance of which the atom is a part. The protons are all alike; it is their number which makes the differences among atoms. The number of electrons in an atom equals the number of protons; the atom as a whole is, therefore, electrically neutral.

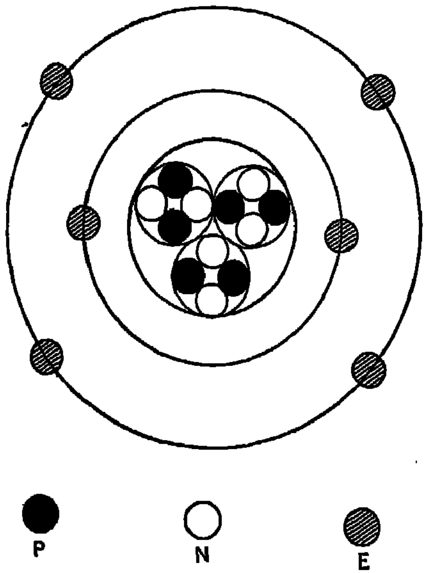


FIG. 1.1. The structure of an atom of carbon. *P*, protons, *N*, neutrons, *E*, electrons. A pair each of protons and neutrons make up an alpha particle.

This concept of the atom leads us to the conclusion that the infinite variety in the world around us is simply a matter of the numbers of protons and electrons in the atomic structure. The greatest number of protons or electrons in any atom is only 94, and the smallest is 1 (hydrogen). The other atoms have numbers in an almost unbroken series in between.

The movements of our muscles, the beating of our hearts, the digestion of our food, the heat of our bodies, and even our thoughts are the result of the motions of atoms of different kinds—carbon, hydrogen, oxygen, etc.—coming together at one moment in different sets and combinations and separating again at another. Chemical change is occurring ceaselessly in our bodies; as Lavoisier, the great

French chemist, said more than a century and a half ago, *"La vie est une fonction chimique."*[1]

Carbon, of all the atoms, is the most characteristic of life.[2] It is the very essence of animal and vegetable matter and has made possible the development of living things. Had the earth been created without carbon, which seems such a commonplace substance, there would have been a desolation of rock and water for all eternity. Never would a tree or even a blade of grass, much less the human race, have come into being.

Molecules.—When two or more atoms become joined together, the particle which results is, of course, larger and heavier than one composed of a single atom. It is then called a *molecule*. For example, sodium (Na) and chlorine (Cl) atoms combine to form sodium chloride (NaCl—table salt); two atoms of hydrogen (H) combine with one of oxygen (O) to form a molecule of water (H_2O); or an atom of carbon (C) unites with two of oxygen to form a molecule of carbon dioxide (CO_2). The molecules so formed, and of course the substances which they constitute, are entirely different in character from the separate atoms. The element sodium is a caustic solid and chlorine a highly irritating and poisonous gas, whereas sodium chloride is a relatively mild and harmless substance essential for most living processes. Again, hydrogen and oxygen are gases, but they unite to form water.

When the molecules of a compound break down into the atoms of which it is composed, the process, or *chemical reaction,* involved is called *decomposition*. When, for example, a compound of mercury and oxygen (a red powder known as mercuric oxide) is heated to a high temperature, the original metal appears. The oxygen with which the mercury was combined is split off from it and escapes. Frequently decomposition and combination proceed simultaneously —e.g., when two compounds are brought together in solution and two compounds quite different from the original ones are formed. Thus, sodium chloride and silver nitrate react to form silver chloride and sodium nitrate. The four types of atoms have undergone a rearrangement. Such a reaction is called *double decomposition.*

[1] "Life is a chemical function."

[2] Charcoal, coal, the diamond, and the "lead" in a pencil are examples of almost pure carbon.

Chemical changes or reactions are, therefore, of three main types—combination, decomposition, and double decomposition.

Molecules may contain two atoms only or a very great number. Very many different kinds of atoms may be present in the larger molecules. It is large and heavy molecules such as these that comprise the protein materials of the living body. The molecules of the fats and of some carbohydrates are also hundreds of times larger and heavier than a molecule of, say, sodium chloride. Could a molecule of certain proteins be enlarged to the size of a pea, the molecule of sodium chloride, if enlarged proportionately, would be no larger than a pinhead.

Molecules are in constant motion. They are ceaselessly changing their positions, moving to and fro, or bouncing about like a number of rubber balls thrown upon a hard floor. In solid materials these movements are less lively than in liquids and gases, and are probably of an oscillatory nature only. In gases the movements have no limits. Air, for instance, is a mixture of the molecules of the three gases—oxygen, nitrogen, and carbon dioxide. And no matter how still the air may appear to be, the molecules are in ceaseless motion, colliding with one another or with solid objects and flying off again in another direction. If confined within a bottle or other vessel, they beat against the vessel's walls and, when allowed to escape, start on an erratic journey which may take them anywhere—even to regions miles above the earth.

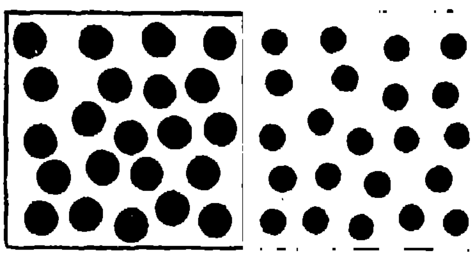
In liquids the motions of the molecules are less rapid, though just as ceaseless. Heat speeds up the movements; cold slows them down. In liquids and in solids the molecules are closely packed; in gases their distances from one another are much greater. By compression the molecules of gas may be brought closer together, and the gas pressure rises; if the molecules are packed densely enough, liquefaction or even solidification of the gas occurs.

Colloids.—When enormous numbers of atoms become grouped together, the molecule becomes so large that it can be faintly seen and its movements detected by an extremely powerful microscope (ultramicroscope). Such huge molecules are also spoken of as *colloid particles* (Gk. *kolla* = glue), and the substance which they compose is called a *colloid*. Often such a molecule is too large to pass through the pores of an animal membrane, such as parchment, frog's skin, or the intestinal wall. The molecules of proteins, starches,

and fats are of such a size. These large molecules have a tendency to cling together, as grains of clay cling together to form lumps. In this way relatively colossal particles are formed.

Colloidal solutions.—Molecules massed together in this way, or even very large single molecules, form solutions which differ in several respects from those of the smaller molecules, of which such substances as common salt, cane sugar, copper sulfate, etc., are made. We therefore speak of these solutions as *colloidal solutions* and of the solutions of salt, cane sugar, etc., as *crystalloid* or *true solutions.*

FIG. 1.2. The change in the relationship between water and colloid particles when a colloid solution stiffens or jellies. On the left the particles are surrounded by water. On the right the water is enclosed by the colloid material.



Liquid glue or gelatin, boiled starch or liquid rubber, india ink, white of egg in water, and blood serum are examples of colloidal solutions. Many colloidal solutions readily change to a more or less solid state when treated in certain ways. When glue or gelatin, for instance, is dissolved in hot water, solidification or jellying occurs when the solution cools. This change in state is due to the fact that the relationship of the colloid particles to the water in which they were dissolved becomes reversed. In the fluid condition the particles are separated from one another and surrounded by the water. In the solid state the particles cannot move, for they have become joined together to form a meshwork which encloses the droplets of water (Fig. 1.2). The fluid state is termed *hydrosol;* the gelatinous state, *hydrogel.*

Brownian movements.—The English botanist Robert Brown in 1828 observed under a powerful microscope random and erratic movements in a colloidal solution. These so-called *Brownian movements* are due to the molecules of water, or the small molecules of crystalloids in the solution, colliding at high speed with the large colloidal particles.

Ions.—When two atoms combine they do so by sharing between them one or more of the electrons in the outer ring of each atom. As long as the chemical substance is in the *solid* state the atoms are held together by electrostatic forces, but the molecules of certain substances, such as sodium chloride (NaCl), hydrochloric acid (HCl), and sodium hydroxide (NaOH), when dissolved in water undergo *dissociation* or *ionization*. That is, the atoms, or certain

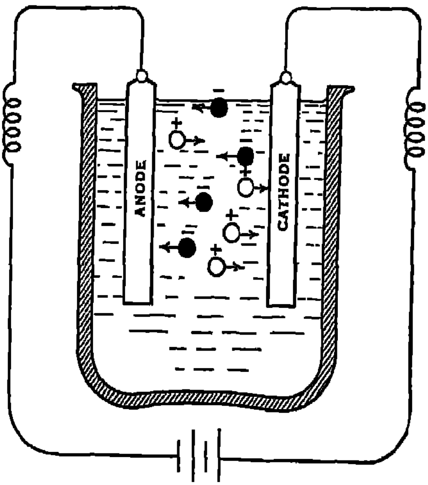


Fig. 1.3. Electrolysis. As an electric current passes through a solution of sodium chloride (NaCl), the positively charged ions (Na^+), or cations, move to the cathode and the negatively charged ions (Cl^-), or anions, to the anode.

groups of atoms, separate from one another and become electrically charged. When sodium chloride, for example, is dissolved in water, the sodium atom loses an electron—i.e., a negative charge—to chlorine and, consequently, becomes electrically positive. The chlorine atom, since it gains an electron, becomes electrically negative. Such charged atoms move swiftly through the solution and are called *ions* (Gk. *ion* = going).

Other substances behave in a similar manner. Hydrochloric acid dissociates into the positively charged hydrogen ions (H^+) and the negatively charged chlorine ions (Cl^-), and sodium hydroxide into positive sodium ions (Na^+) and negative hydroxyl ions (OH^-). Water itself is very slightly dissociated into H^+ and OH^- ions.

Substances whose molecules behave in this way when dissolved in water are called *electrolytes*. When an electric current is passed through a solution of an electrolyte, the negative ions (−) travel

to the point where the current enters the solution (*anode*) and the positive ions (+) move to the point where the current leaves the solution (*cathode*). The negative ions are therefore called *anions* and the positive ions, *cations*. Thus, when a current passes through a solution of sodium chloride (NaCl), the sodium cations (Na^+) collect at the cathode and the negative ions (Cl^-) at the anode (Fig. 1.3).

Diffusion.—When two solids are placed in close contact no interchange of molecules takes place between them. But when two samples of a gas of different concentrations are brought together, molecules of the sample with the higher concentration move to the one with the lower concentration until the molecules are evenly mixed and the two samples are of uniform concentration. Thus, when a pungent gas, such as bromine, is released into a closed room, it can be smelled after a time in all parts of the room even though there are no air currents to mix it with the air. This process, which also occurs, though much more slowly, between certain liquids and substances in solution, is due to the spontaneous movements of the individual molecules or ions and is called *diffusion*. Crystalloids diffuse rapidly as compared with colloids, which do so very slowly or not at all.

Dialysis.—It has just been stated that, whereas crystalloids are readily diffusible and will pass through a membrane such as parchment, the colloids, which are non-diffusible, are held back. It is possible, therefore, to separate crystalloids from colloids in a solution containing both. The process of separating these two substances by means of a membrane is called *dialysis*.

Let us suppose that a bag or tube of parchment is filled with a solution of sodium chloride and a colloid, such as gelatin, and immersed in water or a weaker solution of salt. The molecules of salt pass rapidly through the membrane from the stronger solution to the water, or weaker solution, surrounding the bag. Water molecules pass in the opposite direction to take the place of the salt molecules. This interchange of molecules continues until the solutions on the two sides are of uniform concentration. If the solution surrounding the bag is repeatedly removed and replaced by pure (i.e., distilled) water, the salt is finally completely removed from the solution within the bag, leaving only the colloid material.

Osmosis, osmotic pressure.—Membranes differ considerably with respect to their permeability to molecules of various sizes. Some allow the passage of small molecules of water and crystalloids but are impermeable or nearly so to the larger colloid molecules. Other membranes again, although permeable to water molecules, are impermeable to the larger ones, such as those of salt or sugar. A membrane which will permit the transfer of water but not of a substance dissolved in the water is called semi-permeable to that specific solution. Such a membrane behaves as though it were a sieve with a mesh or openings of a certain definite size. Any molecule smaller than the openings will pass through; larger molecules will be barred.

Now if water should be separated from a solution of sugar by a semi-permeable membrane which allows water but not the sugar molecules to pass through it, water will pass into the sugar solution but the sugar molecules cannot pass out. The sugar solution becomes diluted and increases in volume, and if it were in a tall narrow container its level would rise, i.e., its pressure would be increased. The sugar molecules act as though they "attracted" or "drew" the water molecules across the membrane. This process in which water is transferred across a semi-permeable membrane is called *osmosis,* and the pressure thus created is called the *osmotic pressure.* By means of an *osmometer,* a specially constructed chamber made of rigid walls and a membrane supported by resistant but porous material, enormous pressures can be developed through osmosis (Fig. 1.4). The greatest pressures are developed by solutions of crystalloids; the pressure developed by colloids is very small.

Water molecules always pass through a semi-permeable membrane from the weaker to the stronger solution. The stronger solution has the greater osmotic pressure and is called *hypertonic;* the weaker solution is called *hypotonic.* Two solutions are said to be *isotonic* if they exert equal osmotic pressures. When isotonic solutions are placed on either side of the membrane, no water accumulates on either side and no osmotic pressure is developed.

Osmosis in vital processes.—The principles of dialysis, osmosis, and osmotic pressure are of the utmost importance in living processes. The structures of the body are made up of 70 to 90 percent water, in which are dissolved many crystalloid and colloid substances. Food elements, minerals, enzymes, vitamins, and hormones

pass by diffusion from the blood through the walls of the capillaries into the fluids surrounding these vessels and bathing the cells of the tissues. The envelopes of the tissue cells and the walls of the capillaries themselves are semi-permeable membranes of different types; thus they act in a selective manner toward the various substances dissolved in the blood and body fluids. Osmosis, therefore,

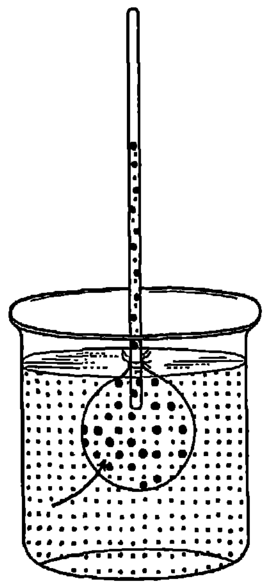


FIG. 1.4. Osmotic pressure. A sac formed of a semipermeable membrane is fastened to one end of a glass tube. The large dots represent sugar molecules, the small ones, water molecules. Water passes through the "pores" of the membrane as indicated by the arrow. The pressure within the sac rises as shown by the height of the fluid column in the glass tube.

enters largely into the processes involved in the interchange of fluid between the blood and the fluid of the tissues, as well as between the tissue fluid and the interior of the cells. It plays an essential part as well in the production of urine. The absorption of water from the soil by the roots of plants and trees and the rise of sap in the stems and trunks also depend to an important degree on osmotic forces.

Acids and bases. Hydrogen-ion concentration. *p*H.—Everyone knows in a general way the characteristics of an *acid*. Acids have a taste usually described as sour—like vinegar or lemon juice; they turn blue litmus paper red. Lye (sodium hydroxide) and slaked lime (calcium hydroxide, used in making mortar) are common examples of *bases*. They have usually a bitter taste and turn red

litmus blue. Lye and certain other bases are also called *alkalies*. The terms *basic* and *alkaline* are, therefore, often used interchangeably. Strong solutions of both acids and bases are highly destructive to animal and vegetable tissues.

Acids and bases combine to form compounds called *salts*, which are neither acid nor basic. Thus,

$$\underset{\text{(hydrochloric acid)}}{HCl} + \underset{\text{(sodium hydroxide)}}{NaOH} \rightarrow \underset{\text{(salt)}}{NaCl} + \underset{\text{(water)}}{H_2O}.$$

Acids and bases therefore neutralize one another.

The term *reaction* is used in referring to the acid or alkaline character of a chemical or its solution; the term is applied as well to the body fluids. Hydrochloric acid, vinegar, urine, and sweat have an acid reaction, whereas lye, lime, blood, milk, and the tissue fluids are alkaline in reaction. A neutral reaction is one which is neither acid nor alkaline.

The true acidity or alkalinity of a solution depends upon its concentration in free hydrogen or free hydroxyl atoms (i.e., in hydrogen or hydroxyl ions). (See p. 8.) A 10-percent solution of hydrochloric acid is more acid than a 10-percent solution of acetic acid. The hydrochloric acid tastes more sour and is more destructive to living tissues. This is because it has a higher concentration of hydrogen ions. Nearly all (80 to 97 percent) of the molecules of hydrochloric acid are dissociated into hydrogen ions (H^+) and chlorine ions (Cl^-), whereas the molecules of acetic acid are dissociated to a relatively small degree (1.4 percent).

An alkaline solution also contains hydrogen ions but in very low concentration; the hydroxyl ions are greatly in excess. An acid solution contains hydroxyl ions but only in relatively low concentration. In a neutral solution the concentrations of the two kinds of ions are equal. It follows, then, that the acidity, alkalinity, or neutrality of a solution can be expressed by stating its concentration in hydrogen ions alone, the hydroxyl-ion concentration being disregarded. The sum of the concentration of H and OH ions is always the same; when the concentration of one ion is high, that of the other is correspondingly low.

It has become customary to express the hydrogen-ion concentration by the symbol *p*H and a figure from 0.00 to 14.00. Water or

a neutral solution is *p*H 7.00. The acidities range downward from this to *p*H 0.00; the alkaline range is upward to *p*H 14.00. The numbers, it will be seen, run in reverse order to the H-ion concentrations. The lower the *p*H the greater is the hydrogen-ion con-

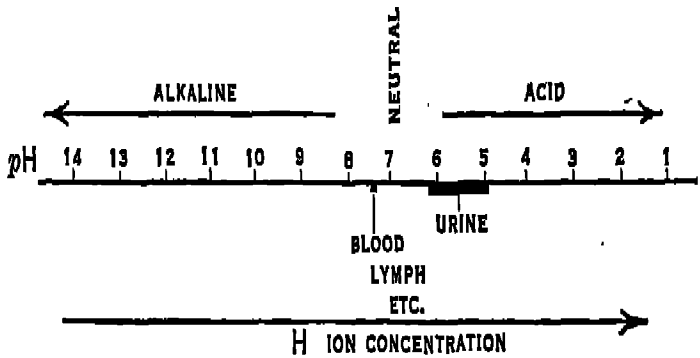


FIG. 1.5.

centration and the greater the acidity. Thus, a solution of *p*H 1.00 has a greater H-ion concentration than one of *p*H 6.00 and is, therefore, more acid. Moreover, the *p*H 1.00 solution has not simply six times the H-ion concentration of *p*H 6.00 but several thousand times more.

In the same way, *p*H 14.00 indicates a much lower H-ion concentration, and consequently a much more alkaline solution, than *p*H 8.00 (Fig. 1.5). The blood and body fluids are slightly alkaline —about *p*H 7.40.

chapter 2

PROTOPLASM

Protoplasm is the stuff of which all living things are made. Anything composed of protoplasm is or has been alive. It is necessary, then, that we should know all we can about a substance that constitutes the very essence of living matter—a substance that goes to the making of a green leaf, of a worm, or of a man. The "stuff and substance" of brain, muscle, bone, and sinew is protoplasm.

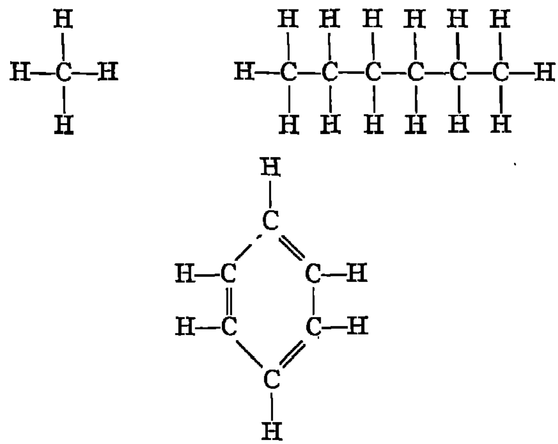
Protoplasm is a gelatinous substance composed largely of water (about 75 percent) and protein (about 25 percent). It is structureless and actually fluid, for under a powerful microscope particles can be seen to move through it more or less freely. The streams or currents that can sometimes be seen within its substance also indicate its fluid nature. Besides protein it contains various essential minerals—calcium, sodium, potassium, magnesium, etc.—and small amounts of sugar (glucose), starch (glycogen), and fatty materials.

Proteins are colloids—that is, large molecules grouped together or very large single molecules. Protoplasm is, then, a colloidal solution, and like such solutions, it changes to the solid state under certain conditions. After death it loses its fluid nature. Protein molecules are made up of the atoms of carbon, nitrogen, oxygen, and hydrogen, some sulfur, and usually a little phosphorus. To the carbon, protoplasm owes its wonderful versatility. Without carbon, life in the numberless forms in which we know it could never have evolved. Carbon atoms, unlike the atoms of any other element, have the extraordinary ability to link themselves into chains and rings and to add to these the atoms of other elements. When it is recalled that the addition of a single atom to a molecule may completely change its character, one can realize what tremendous pos-

sibilities for variation in form, minute structure, and function are bound up within protoplasmic material.

The modern chemist makes use of this characteristic of the carbon atom, and in his laboratory imitates in a measure the wonders which through the ages nature has wrought from protoplasm. Using a raw material derived from prehistoric life—coal tar—he links the carbon atoms into rings and chains to create substances differing widely in their properties—antiseptics, anaesthetics, headache powders, perfumes and flavors, various brilliant dyes, plastics, photographic materials, and many other things in general use today. Or, starting with cotton or wood pulp (cellulose) and attaching nitrogen, sulfur, or other atoms here or there to the carbon, he can make explosives, celluloid, paints, or artificial silk.

Below are shown some of the ways in which carbon atoms link themselves and other atoms together.



The structure of the molecule of a coal-tar (aniline) dye is given in Figure 2.1.

The loss or addition of an atom from or to a molecule will alter its entire nature. The mere change in position of one of the atoms will do the same. The number of ways in which the atoms making up protoplasm—carbon, hydrogen, oxygen, nitrogen, and sulfur—can be combined is unlimited. Indeed, the chemical compounds which nature might create from these atoms exceed in number the stars in the Milky Way. So it may be realized how nature's laboratories have,

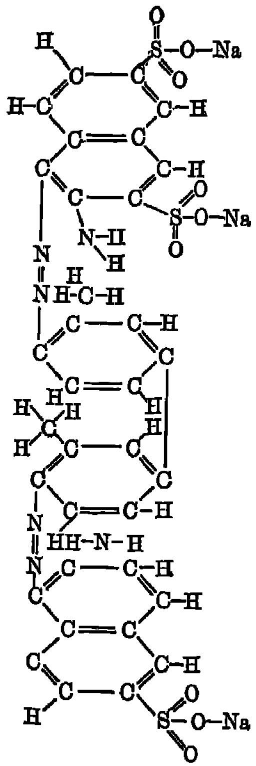


FIG. 2.1. Formula of an aniline dye, showing the complicated arrangement of the great number of carbon, hydrogen, nitrogen, and other atoms.

from this raw material, produced types of life infinitely varied in structure and function.

THE DIVISIONS OF PROTOPLASM

Microscopic life.—Until some 300 years ago the muscles, skin, bone, and other tissues of our bodies were thought to be little more than lumps of material, without any fine texture or structure. They were supposed to be simply masses of pulp, without any division into small pieces. It is not surprising that this should be the belief of the scientists before the seventeenth century, since no one then could look into a piece of muscle or skin or liver and see just how it was made up. A Dutch biologist, Antony Leeuwenhoek, was one of the first to use the microscope to examine all kinds of living things (Fig. 2.2). His long brass tube, with a lens at either end, was a very poor affair compared with the powerful microscopes of today, which magnify the object thousands of times. But to Leeuwenhoek it was a miracle-worker, a weaver of fantastic tales—but tales that, strange and weird and almost unbelievable as they were, nevertheless were true. This lens brought him worlds that had been closed to all eyes since the beginning of time. So absorbing and fascinating were the dramas which unfolded before his eyes that he gave up his life to the study of this world of the "infinitely little." His great work describing what he had seen was published in 1669.

Nothing was too commonplace for him to examine; little escaped his scrutiny, and nothing was examined that did not furnish its surprises. Dust, earth, sea water, ditch water, all showed millions of

tiny forms of life—little animals—*animalculae* he called them. Everywhere was teeming life; almost nothing was quite motionless. Blood was no longer what it appeared to be to the naked eye—simply a richly red fluid—but was a sickly yellow stuff, in which floated pink coin-shaped bodies—the *corpuscles*—which were whirled along like tiny rafts through finely delicate channels. We now call these channels *capillaries*.

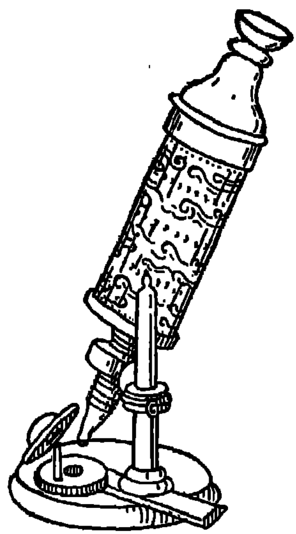


FIG. 2.2. Microscope used by scientists of the 17th century.

Cells.—It was later discovered that the tissues of our bodies which make up the muscles, skin, kidney, heart, liver, or other organs were not textureless but were made of a delicate fabric of millions upon millions of rounded, squarish, slender, or twisted bodies, each of which in itself looked like some of the separate little animals which the first microscope had revealed. These bodies we call *cells*. We now know that these cells are composed almost entirely of protoplasm, and we know that they are used, together in sheets, tubes, or rounded masses as in a tiled floor or in a piece of masonry to form the many different parts of our bodies. It was not until 1838, more than a century after Leeuwenhoek's day,

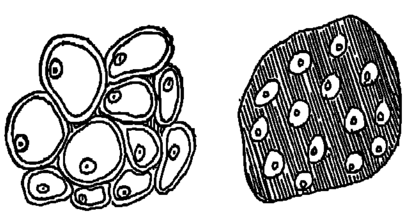


FIG. 2.3. A reproduction of one of the published drawings of tissue cells.

that a cell of the body was clearly described. One of the earliest published illustrations of tissue cells is shown in Figure 2.3.

Cells, though of many different types, sizes, and shapes, resemble one another in their appearance. The general plan of structure is

the same in all. In order that the reader may form an idea of the cell's structure, we cannot do better than describe the *amoeba*—a microscopic animal found in ponds and ditches. Its entire body consists of but a single cell (Fig. 2.4).

The amoeba.—The amoeba is a tiny piece of protoplasm; yet when pinched, pricked, or touched with something hot or with a crystal of salt, it shows by a movement that it is alive. It is therefore said to be *irritable*. This is a word which physiologists use in a very special sense to denote the reaction of a living thing in response to a change in its environment. Such a change is called a stimulus. Technically, then, the word *irritable* means the ability to respond to a stimulus.

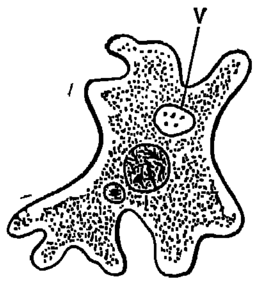


FIG. 2.4. An amoeba. A description is given in the text. V, vacuole.

The amoeba breathes and digests food, rids its body of waste materials, and moves from place to place. Yet no particular part of its body has been set apart as lungs, stomach, kidneys, or limbs. The protoplasm of which its body is molded is a jack-of-all-trades. It can do all these things, which in higher animals are performed by special organs. The amoeba's entire body or any part of it may be given over to the task at hand, whether this be seizing and digesting its food, moving from one place to another, breathing, or ridding itself of waste materials.

Though the tissues of the human body, whether nervous, muscular, glandular, or what not, are built mainly of protoplasm, this material has undergone in each type of tissue certain changes which make it especially capable of performing a single function.

Under the microscope the amoeba appears as an irregularly shaped scrap of living jelly. The irregular outline of the cell can be seen to change from time to time, and, as we watch, we soon see that there is a purpose in these changes. One or two little peninsulas of protoplasm will be seen to jut out from the amoeba's body into the water surrounding it. These protrusions of protoplasm are called *pseudopodia* (Gk. *pseudopodium* = false foot). At another moment the pseudopodium is drawn back, only to be thrust out again at another part of the amoeba's circumference. The movements enable

the animal to get at its food or to move away from a spot which is not suitable for it to live in. Figure 2.5 shows an amoeba chasing a small globular organism and trying to engulf it. The white cells in human blood and in some other tissues of the body are able to move about in the same way, but most of the cells of the body are firmly fixed.

In or near the center of the amoeba can be seen a somewhat rounded object which remains distinct from the main body of the

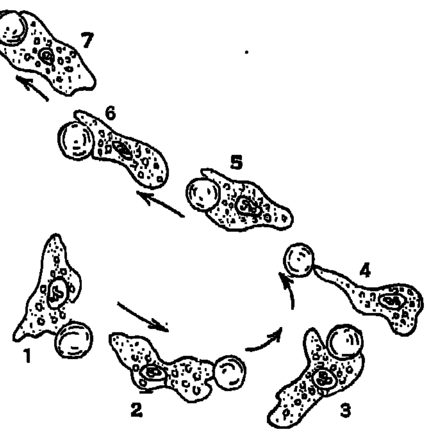


FIG. 2.5. An amoeba endeavoring to engulf a small organism, which, on account of its shape, slips from the amoeba's grasp. The arrows indicate the course of the chase. (*After Jennings.*)

cell. This is called the *nucleus*. The body of the cell surrounding the nucleus is called the *cytoplasm*. There is to be seen within the cytoplasm, usually not far from the nucleus, a small cavity called a *vacuole*, which constitutes the digestive system of the amoeba. Enzymes poured into it from the cytoplasm digest food particles which the organism has captured. The vacuole can be observed to alter in size and shape from time to time as a result of contractions of the surrounding cytoplasm.

When the amoeba is killed and its body stained with a blue dye, it is found that the nucleus stains much more deeply than the cytoplasm. The reason for this difference is that the nucleus contains a material called *chromatin*, which absorbs the dye more readily. The chromatin material appears as dark-colored threads or strands, which interlace in a complicated way with one another to form a fine network within the nucleus. Though the outline of the amoeba changes from time to time, none of its substance becomes

lost; that is, the cytoplasm does not become dissolved by the water to disappear gradually, as a small piece of ordinary jelly would be, but clings together. This is because the amoeba, like the cells of which our bodies are made, possesses some firmer material at its boundary—a kind of *membrane*—which prevents the cytoplasm from breaking up and disappearing. This outer layer is also frequently referred to as the cell envelope or cell wall.

With the exception of the vacuole, the different parts described above for the amoeba—namely, the nucleus with its chromatin, the

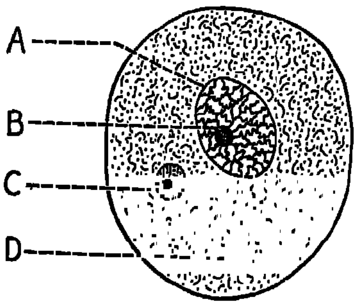


FIG. 2.6. A typical cell. A, *nucleus;* B, *nucleolus;* C, *centrosome* with *centriole;* D, *cytoplasm.* This drawing is semidiagrammatic and shows the cell in two dimensions only, but it must be remembered that the cell has depth as well as breadth. Some are globular, others cubical or disk-shaped.

cytoplasm, and the cell membrane—are to be found in nearly all animal cells.[1] Most cells also possess a small body, called the *centrosome,* situated in the cytoplasm close to the nucleus. When the cell is stained with a suitable dye, a minute structure—the *centriole*—is seen near the center of the centrosome. Figure 2.6 shows a typical cell of the body of a higher animal.

TISSUES AND CELLS

Different parts or organs of the body behave differently. The duties which one type of tissue has to perform are quite different from the duties performed by another type. The reason that one tissue or organ, such as the stomach, can digest food, and another organ, such as a muscle, can move a limb, is that the cells of which each organ is made are different. We have four main types of cells—epithelial, muscular, nervous, and connective. The term *tissue* is a very general one, applied to any material derived from animal or

[1] The only exception to this is the fully developed red blood cell of man and higher animals, which has no nucleus.

vegetable life and consisting of cells which are grouped together in masses. When it is desired to be more explicit and to indicate the general type of cell of which a certain tissue is composed, the name epithelial, muscular, nervous, or other qualifying term is added. Thus we speak of epithelial tissue, muscular tissue, nervous, fatty, and bony tissues, etc. More specific terms, such as liver tissue, kidney tissue, etc., are also used.

The epithelial tissues.—The epithelial tissues serve chiefly the purposes of protection. They cover the surface of the body (skin)

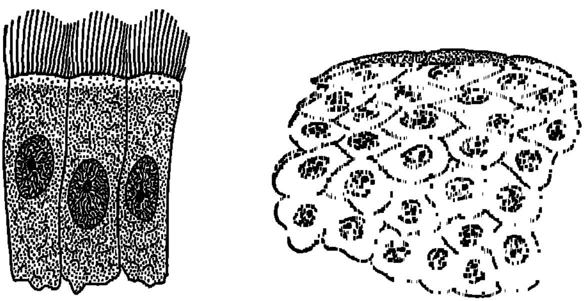


FIG. 2.7. *Left:* Three epithelial cells. *Right:* Several layers of epithelial cells from the mucosa of the urinary bladder. Semidiagrammatic. The superficial layer is of the squamous type; deeper cells are cuboid in shape.

and line the nose, throat, windpipe, stomach, and intestines. The various glands of the body are also composed of epithelial cells which have acquired special powers to manufacture juices (secretions). Typical epithelial cells are oblong in shape and appear under the microscope as slender columns, set side by side in rows like the stakes in a palisade. The term *columnar* is given to epithelial cells of this type. They are often, as in the case of the cells lining the nose and throat, surmounted by delicate hairlike structures called *cilia* (Fig. 2.7, *left*). The cilia, which are about $\frac{1}{3500}$ inch long, sway continuously to and fro so that their surface looks like a wheat field undulating in a breeze. The waves, however, travel only toward the exterior—upward in the lower air passages and downward in the nose. Thus, the cilia serve to sweep dust and other small particles and mucus from the surfaces of the air passages.

Sometimes epithelial cells are more like cubes in shape. Then the term *cuboidal* is applied to them. In some regions, such as the skin,

the covering of the eyeball, and the walls of the air sacs in the lungs, they are flat and scale-like. This type is called *squamous* (L. *squama* = a scale). (See Fig. 2.7, *right.*)

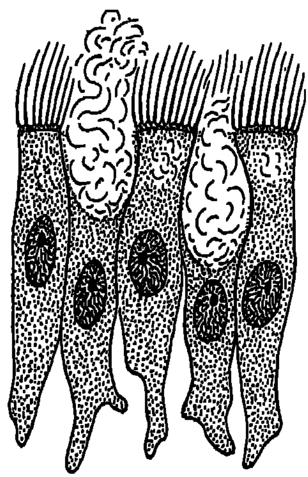


FIG. 2.8. Five goblet cells. Two are discharging mucus.

The linings of the nose, throat, windpipe, stomach, and intestines are called *mucous membranes*. They consist of a layer of epithelial cells lying upon a foundation of connective tissue and a few muscle cells. Many of the epithelial cells in these situations form drops or globules of mucus—an almost clear, watery, or somewhat slimy fluid—within their bodies. The globules burst from time to time and pour their mucus upon the surface of the mucous membrane. Epithelial cells of this nature are in reality like little *mucus glands*. From their appearance when filled they have received the name goblet cells (Fig. 2.8). When the cells are inflamed, their secretion is increased many times. We are all familiar with the "running" nose of the common cold and with the expectoration of mucus which accompanies a "cold in the chest." The thick fluid comes from the goblet cells.

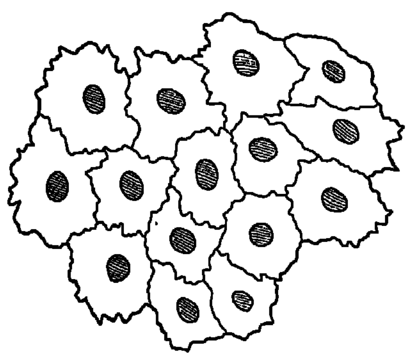


FIG. 2.9. Endothelial cells.

One type of epithelial cell is extremely thin, being no more than .0001 inch thick. Such cells are found laid edge to edge to form delicate linings for the arteries, veins, and heart. The smallest blood vessels, the capillaries, are tubes composed entirely of a single layer of these cells. These cells also cover the membranes of the thorax (*pleurae*), of the abdomen (*peritoneum*), and of other cavities.

The name *endothelial* is given to this type of epithelial cell (Fig. 2.9).

Nerve cells.—Nerve cells consist of a body and two long, slender arms called *processes.* One of these arms is called the *axon,* the other the *dendron* or *dendrite* (Figs. 29.1 and 29.2). The axon carries messages from the cell to various parts of the body. The dendron carries nerve messages or *impulses* in the opposite direction—that is, from some one or other region of the body to the nerve cell. Nervous tissue will be considered in greater detail when the functions of the brain and spinal cord are dealt with (p. 269).

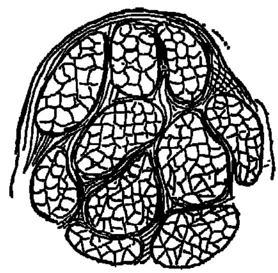


FIG. 2.10. Cross section of a bundle of muscle fibers.

Muscle cells.—Muscle cells have the special ability to shorten (contract) when stimulated. On account of their great length and slenderness, they are usually referred to as *muscle fibers.* Large numbers of such fibers are grouped together in bundles. The bundles are bound together by connective tissue to constitute the large muscles of the arms, legs, etc. The power of a muscle depends upon the combined effect of all its microscopically small fibers contracting at the same time (Fig. 2.10).

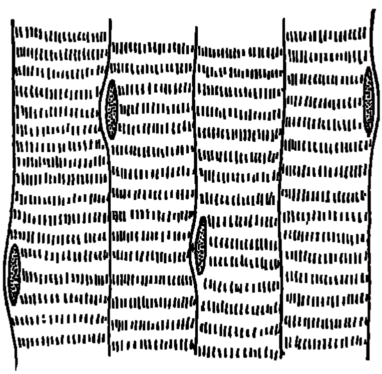


FIG. 2.11. Striated cells (fibers) of voluntary muscle.

The fibers of voluntary muscle—the biceps, for example—show transverse stripes or, as they are more commonly called, *striations* (Fig. 2.11). Involuntary muscle fibers—those of the stomach, intestine, and the small arteries, for example—though they show fine and ill-marked longitudinal striations have no transverse markings. They are therefore called *non-striated, unstriped,* or *smooth* (Fig. 2.12).

In the matter of striation the heart muscle is an exception, for though it is involuntary, it is cross-striated (Fig. 2.13). But unlike

skeletal muscle, the fibers are connected with one another through slips or bridges.

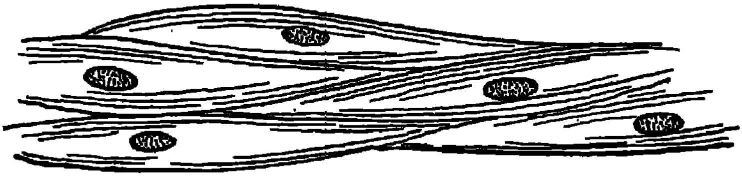


FIG. 2.12. Unstriated cells (fibers) of involuntary or smooth muscle.

Connective tissue cells.—Connective tissue cells are so long and slender that often nothing more than a number of long-drawn-out threadlike fibers can be seen (Fig. 2.14). This tissue, as its name implies, serves to connect other masses of cells. Connective tissue cells lie between nerve and muscle cells and beneath the sheets of epithelial cells. They form, with fat cells, a thick layer beneath the skin, or they fill up spaces in various parts of the body which are not occupied by any more specialized type of cell.

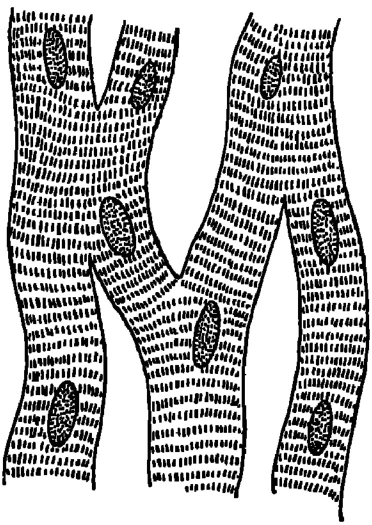


FIG. 2.13. Striated cells of cardiac muscle. Note the bridges of protoplasm connecting neighboring cells.

Connective tissue not only serves as the "filler tissue" of the body but also binds together and gives strength and firmness to the various softer tissues. The fibrous tissues in the walls of organs such as the stomach, the tendons of muscles, and the ligaments binding bones together are all composed of connective tissue cells.

These cells in certain regions become changed for the special tasks which they are called upon to perform. The cells of bone, for instance, belong to the connective tissue class, but the bodies of these cells are so specialized that they are able to take large quantities of minerals, lime, and phosphorus

from the blood (Fig. 2.15). With these minerals they form strong, unyielding parts (skeleton) for the support of the soft tissues.

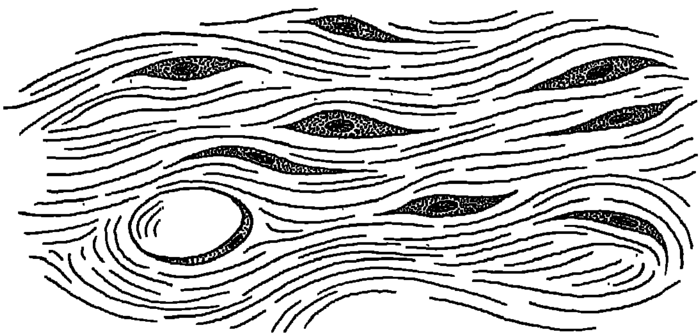


FIG. 2.14. Connective tissue. A single fat cell is shown on the left lying between the connective tissue fibers.

Fatty or *adipose* tissue is made up of connective cells which have become loaded with droplets of fat (Fig. 2.16).

Cartilage, or gristle as it is often called, is a special type of connective tissue which covers the ends of the long bones where they

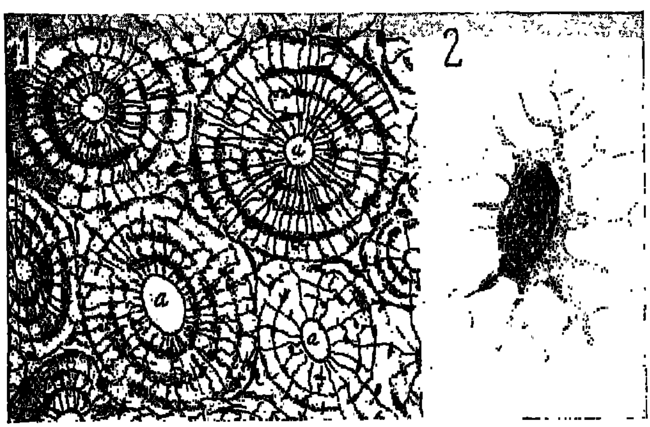


FIG. 2.15. A section of bone. 1. Fine canals, *a,* surrounded by bone cells in which the minerals calcium and phosphorus are deposited. 2. An enlarged drawing of a bone cell.

come together to form joints (Fig. 2.17). This material, in the form of disks, also lies between the vertebrae. It comprises the

larynx, the ear, and the tip of the nose, and joins the ribs to the breastbone.

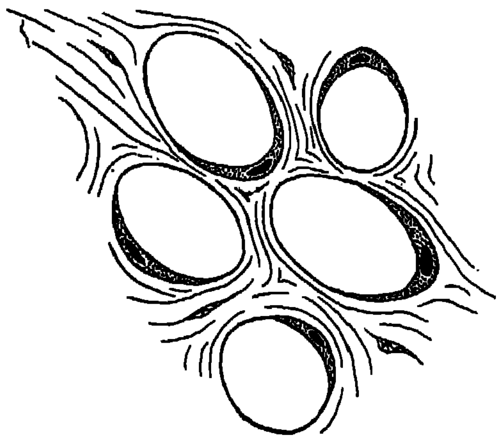


FIG. 2.16. Adipose tissue. Note the displacement of the nuclei of the fat cells to the boundary of the cell by droplets of fat.

In *elastic tissue* the connective tissue fibers are easily stretched but recoil to their former length when the stretching force is removed. This tissue is employed for the formation of ligaments, which bind together the bones of movable joints, such as the ankle, spinal column, etc. It is also found in the walls of the arteries and in many other organs.

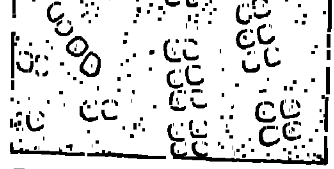


FIG. 2.17. A section of cartilage.

THE PHYSIOLOGICAL PROPERTIES OF PROTOPLASM

Protoplasm in its simplest form, as in the body of the amoeba, is endowed with four abilities. It is just these abilities which we recognize as the outward and visible signs of life. They are: *irritability* (which, as has been explained, is the power to react to a stimulus), *growth*, *metabolism*, and *reproduction*.

In higher forms of life, protoplasm as a whole has lost the self-sufficiency which it retains in the lower forms. Persons in a modern civilization no longer grow their wheat, grind their flour, and bake

their bread. They no longer clothe themselves in homespun garments, or fell the trees and hew the timber for their dwellings. Each of these different tasks is performed by specially trained persons who are generally of little use in fields other than their own. So it is with protoplasm when it becomes "civilized" and comes to live in rows upon rows of cells. No longer can any one type of cell perform all the vital duties, as the amoeba does. Labor is divided, and certain groups of cells become highly trained for special purposes. Nerve and muscle cells, for instance, have, so to speak, educated themselves to respond very quickly to stimulation. They are consequently called the *irritable tissues.* They cannot, however, reproduce themselves, and it is only in early life that they grow. In higher animals and man a special group of cells is set aside for reproduction. The simple amoeba, on the other hand, in order to reproduce its kind simply divides into two.

Figure 28.5 shows a section of kidney tissue. The cells, though of the epithelial class, have become highly specialized for their duty of forming urine. The cells of the liver and of other organs have also become modified to the end that each may perform its own special work with the greatest degree of efficiency.

Living cells of all kinds, whatever their duties, are tiny chemical laboratories. Within their protoplasm are carried out the most complicated chemical reactions—oxidations, decompositions, and combinations of various types. By these reactions heat is evolved. In fact, we may compare each cell to a furnace of microscopic size. When a handful of sugar is thrown into the fire and flames up, we say that it has burned, or has undergone combustion or oxidation. Fat, too, makes a great blaze and gives out a great deal of heat. Meat burns with greater difficulty, but nevertheless it will soon be consumed if thrown into a hot fire.[2] We know that oxygen is necessary for the burning of these substances and that carbon dioxide is formed.

Much more slowly but in very much the same way the foodstuffs are oxidized in the innumerable cells of our bodies. The carbon of the food is oxidized to carbon dioxide and the hydrogen to water. The heat produced keeps the body warm, maintaining its

[2] Though fats and sugars are completely "burned" in the body, protein (pp. 240 and 242) undergoes only partial combustion. The nitrogen of the protein remains unconsumed and is removed mainly as urea by the kidneys (p. 256).

temperature constant at about 98.6°F. Thus, when we say that a certain food is *metabolized,* we mean that it is oxidized by the cells of the tissues, with the production of heat. The process itself is called *metabolism*. The heat produced is expressed in Calories.

Metabolism, however, embraces chemical processes other than the oxidation of food. The cells take from the blood the substances they require and manufacture entirely new materials. The cells of the digestive glands, for example, form secretions of various sorts containing enzymes and acids or bases; other complex and very powerful substances known as hormones are formed by the cells of the endocrine organs (p. 399). The synthesis of new tissue during growth and for the repair of worn-out tissue parts is also included under the term metabolism. In short, the word comprises all the chemical work performed by living cells.

Chemical functions are not confined to animal cells, for they are performed also by plant life. The yeast cell, for example, converts sugar into alcohol and carbon dioxide. The microorganisms of disease manufacture various poisonous substances called *toxins*. The cells of the mouth glands of poisonous snakes form deadly venoms. All these chemical processes are included under the term metabolism.

How Different Parts of the Body Are Nourished

We have seen how the amoeba obtains its food. But the cells of the body cannot roam about looking for food. They must remain in one place and yet they must be fed. The food must be carried to them. This task is performed by the blood. The blood acts as the waiter who brings the food from the cooks in the kitchen to the guests in the dining room. The cells of the stomach and intestines are the cooks of the body. They prepare the food and give it to the blood, which then gives a little to every cell in the body. Each cell then oxidizes what it receives and gets from it energy to do useful work, much as the steam engine burns coal to drive its wheels.

part II

The Blood and Tissue Fluids

Chapter

chapter 3

THE FUNCTIONS AND COMPOSITION OF THE BLOOD

Approximately 75 percent of the substance of the animal body is made up of fluids. Fluids fill the spaces between groups of tissue cells and bathe every cell. The colorless fluid in these places moves sluggishly, much as water seeps through marshy ground. It is not kept within definite channels or canals and is therefore spoken of simply as the *tissue fluid*. On the other hand, that bright red fluid which we know as blood courses swiftly through a system of tubes—*arteries, capillaries,* and *veins* (Chap. 8). In the largest of these tubes—the arteries—the blood flows at the rate of a mile or more per hour. The blood, however, as we shall presently see, is only semi-fluid; it contains a large number of solid particles—the blood cells—which are evenly mixed with the fluid. The smallest blood vessels—the capillaries—are made of the very thinnest and most delicate of membranes. The wing of a mosquito is a coarse, heavy material compared with the membrane which forms the wall of a capillary. The capillary walls are porous and allow fluid, but not the red cells, to pass from the blood and mix with the fluid in the tissues. They also permit tissue fluid to enter the blood stream and mix with the blood. Thus it can be easily understood how oxygen and nourishing substances are conveyed from the blood to the cells of the tissues, and how, on the other hand, carbon dioxide and waste materials[1] can be carried from the tissue cells to the blood.

The blood flowing through the capillaries, and the interchange

[1] These are unoxidized elements of the food, mostly remnants of protein, such as urea, uric acid, etc.; they are carried in the blood to the kidney and excreted in the urine.

of materials between the fluids of the tissue and of the blood, call to mind a brook trickling through a marshy meadow. The water of the marsh, though apparently still, is kept fresh and sweet, and vegetation flourishes as a result of the revivifying stream flowing through its midst.

The functions of the blood.—In order to understand the functions of the blood, let us study for a moment a creature which is composed of only a single cell, such as the amoeba (p. 18). It lives in water, and the water which bathes its surface serves for this organism those purposes which for higher forms of life, having bodies composed of millions of cells, are carried out by the blood. For example, the single-celled amoeba requires oxygen, and this gas simply passes by diffusion from the water in which the creature lives into the interior of its body. The amoeba forms carbon dioxide, and this gas, as it is produced, passes directly out into the surrounding water. Nourishment is obtained also in this direct and simple fashion, and in the same way waste materials formed within the cell are cast away. Similarly, the amoeba's temperature and its water supply are governed by the water in which it lives.

The human body is composed of millions and millions of cells, each of which is not fundamentally different from an amoeba. The elemental needs of each cell of this community of cells are no greater and no less than those of the one-celled animal. No cell of the body can exist for long without oxygen. Every cell forms carbon dioxide, which must be eliminated from its protoplasm and from the body. Nourishment must be provided upon which each cell may feed, and waste materials must be removed if the cells are not to become poisoned and die. But we know that in the bodies of higher animals the cells are packed together in masses and lie at a distance from the surface. They cannot possibly satisfy their essential needs after the fashion of the amoeba. Some very primitive forms of life, such as the sponges, though made up of many cells, get over the difficulty by the development of canal systems which course through their bodies and open upon the surface. Through these canals the ocean waters in which the sponge lives flow freely in and out to bring oxygen and nourishment to the interior cells and to carry carbon dioxide and waste products away. Such a device may be looked upon as the first attempt at a circulation. It is an open one and, of course, very imperfect. In

higher forms of animal life the circulation is closed, and the channels are filled, not with water, but with a fluid highly specialized for the performance of those duties which every body cell demands.

The functions of the blood and tissue fluids are summarized below.

1. *Respiration.* The transportation of oxygen from the air in the lungs to the tissue cells and of carbon dioxide from the tissues to the lungs (p. 125).

2. *Nutrition.* The conveyance of food materials—glucose, amino acids, and fats (pp. 169-173)—from the intestine to the tissues.

3. *Excretion.* The carriage of waste products from the tissues to the kidney and intestine.

4. *Regulation of the body temperature* (Chap. 26).

5. *Maintenance of the water content of the body.* This duty is shared, of course, by the tissue fluids.

6. *Protection against disease.* The blood and tissue fluids contain certain chemical substances, antitoxins, etc., which are the basis of the body's defense against germs and other injurious agents. The blood also serves as a medium through which hormones (p. 399) manufactured by the several ductless glands are carried to all parts of the body.

The quantity of blood.—The blood in the body of a man of average size has a volume of over 5 quarts.[2] It makes up about 9 percent of the total weight of the body. This quantity varies very little in health.

The composition of the blood.—The blood is a bright red fluid about as thick as milk. It is a suspension of cells—the corpuscles—in a clear fluid. The corpuscles are of two main types—red and white. The red corpuscles are many times more numerous than the white. Both types will be described later.

If blood is shed and collected in a small glass tube, it soon sets into a jelly or *clot.* Certain measures can be taken, however, which will prevent the blood from clotting, and when this is done it will be found that the blood cells, after a time, have settled toward the bottom of the tube, much as finely divided clay settles from water. The setting of the corpuscles can be hastened very greatly by placing the tube of blood in a machine called a *centrifuge.* This machine whirls the tube of blood in a circle in the same way that milk is

[2] U. S. measure.

spun in a separator. When the tube is removed, the blood will be found to have separated into a lower red and nearly solid portion and an upper straw-colored fluid (Plate I*a*). The lower mass is composed entirely of the blood cells, which, being heavier, have been forced to the bottom of the tube. The upper portion is the fluid part of the blood. It is called *plasma*. The plasma of human blood amounts to 55 percent. The cells make up the remaining 45 percent.

The following are the chief constituents of the blood:

A. *Plasma*	
1. *Water*, 92 percent	
2. *Proteins*	Fibrinogen Serum globulin Serum albumin
3. *Inorganic substances*	Chlorides, carbonates, and phosphates Sodium Potassium Calcium Magnesium
4. *Nutritive materials*	Glucose, fats (pp. 170, 171) Amino acids (pp. 174, 177)
5. *Waste materials*	Urea, uric acid, etc. (p. 241)
B. Solid elements	1. *Red cells* or erythrocytes 2. *White cells* or leucocytes 3. *Platelets* or thrombocytes

The plasma.—In composition and general appearance the plasma resembles very closely the fluid filling the tissue spaces and bathing the individual cells. The proteins are dissolved in the plasma in much the same way as gelatin or white of egg, which are types of protein, may be dissolved in a weak solution of salt. The proteins give a certain stickiness or *viscosity* to the plasma, which water or saline alone does not possess. As we shall see later, this viscosity of the plasma aids in maintaining the blood pressure (p. 91).

Since the proteins are colloids, those principles governing the behavior of colloidal solutions (p. 6) apply to the blood plasma.[8]

[8] The capillary wall is a semi-permeable membrane in so far as the proteins of the plasma are concerned (p. 10). The latter, especially the albumin, therefore, exert a definite though small osmotic pressure.

Fibrinogen has a special function to perform in the coagulation of the blood (p. 44). The osmotic pressure of the plasma depends mainly upon the serum albumin. Thus, since water is drawn from the tissues and held within the blood vessels, the volume of the blood is maintained at the normal level (p. 33). From the serum globulin immune substances are manufactured which are essential for the defense of the body against the microorganisms of disease.

The various inorganic constituents of the plasma—sodium, calcium, potassium, phosphates, and sodium bicarbonate—are absolutely essential for the proper functioning of the body cells. The proportions of these several salts do not vary appreciably in a healthy individual, and serious disturbances arise if their percentages rise above or fall below the normal level.

When a specimen of living tissue is removed from the body of an animal for study, it must be kept moist or it will die almost immediately. Pure water, since it does not contain the essential salts, is not suitable for this purpose, and the cells are killed. A watery solution may be made up containing sodium chloride, calcium chloride, and potassium chloride in the same proportion as they exist in the plasma. This fluid, known as Ringer's solution, after the physiologist who first used it, when employed to bathe the tissue, keeps it alive and capable of performing its normal functions for a comparatively long time. Sodium bicarbonate is added to the solution to neutralize acids which are formed in metabolic processes and thus maintain the alkalinity of the blood and other fluids of the body.

The glucose, fats and fatty acids, and amino acids in the plasma are the food materials being carried to the tissues of the body. Some of these materials supply the energy for the performance of work, others go to build up the body of the growing animal, and still others are used to repair the wear and tear of the tissues. These substances are derived from the starches, sugars, fats, and proteins of the food which has been digested in the stomach and intestines. Urea, uric acid, and other waste materials derived from the protein of food and body tissues (p. 260) are excreted in the urine.

chapter 4

THE RED BLOOD CELLS. HEMOGLOBIN. ANEMIA. BLOOD CLOTTING. HEMORRHAGE. TRANSFUSION. CARBON MONOXIDE POISONING

THE RED CELLS OR ERYTHROCYTES

The red cells of the blood are called *red blood corpuscles* or *erythrocytes* (Gk. *erythros* = red; *kytos* = cell).

Under the microscope they appear as pink disks. They owe their color to a pigment called *hemoglobin,* which will be considered in more detail later. The deep red color of blood as seen by the naked eye is due to the great numbers of these pigmented cells massed together. The mature human erythrocyte is different from any other cell of the body in that it possesses no nucleus.[1] If the cell is examined carefully under the microscope, a shallow, saucerlike depression can easily be made out in its center (Plate I*b*). The depression or hollow occupies the greater part of the body of the cell and is present upon both surfaces, making the cell much thinner toward the center than around its circumference, which forms a circular lip. As a consequence the translucent cell, when seen edgewise, has an outline something like a dumbbell or a doubly clubbed rod.

The size and number of red cells.—The red cell is about 1/3000 inch in diameter and no more than .0001 inch thick.[2] Looked at under the microscope, a film of blood appears as a mass of these

[1] The red corpuscles in the blood of some lower forms—e.g., the frog—contain a nucleus.

[2] These measurements are more usually expressed in microns (μ). A micron is 1/1000 millimeter. The diameter of the red cell is 7.2 microns and its thickness 2.2 microns.

small rounded objects, crowded together so that each one touches, or almost touches, its neighbor. Sometimes the cells cling together with their broad surfaces applied to one another, and the edges only are seen, so that they resemble a pile of coins. Such an arrangement of the cells is spoken of as a *rouleau* (Plate I*b*).

A cubic millimeter of a man's blood contains from 5 to 5½ million red cells. A cubic millimeter is about 1/25 drop. The blood of a woman contains about half a million fewer cells per cubic millimeter than the blood of a man. The number of cells in all the blood of a man of average size is no less than 25 trillion (25,000,000,000,-000). If laid flat, edge to edge and one layer deep, all the cells in the human body would cover an area of about 3,500 square yards.

The life history of the red cells.—The red cells are manufactured by the *red marrow* at the ends of the bones of the legs and arms and in the red marrow of the ribs and vertebrae (Fig. 4.1). The cell develops through several stages before it is finally turned out a finished product into the blood stream. In its earliest stage it is a very large cell and has a large nucleus but contains no pigment. Later it becomes smaller, gains hemoglobin, and finally loses its nucleus. In a healthy man it does not escape from the bone into the general circulation until it has reached this last stage. The cells of this stage—that is, the youngest cells in the circulation—show, when stained with a special dye, a fine blue network or reticulum. They are therefore called *reticulocytes*. They soon lose this reticulated appearance, becoming mature erythrocytes within a few hours after their discharge from the bone marrow.

The erythrocyte has a short life. It is driven completely around the body at high speed once or twice a minute and is subjected to many stresses and strains. It becomes old and worn out in service and finally breaks up in the blood stream. Its life span has been estimated at 90 to 125 days. The fragments of the worn-out cells are removed from circulation by certain large scavenger cells in the spleen. Fresh erythrocytes are turned out by the bone marrow to replace the millions of cells which disappear each day.

Hemoglobin

The pigment of the red cell is a complex protein called *hemoglobin*. It is the all-important constituent of the cell. Without hemo-

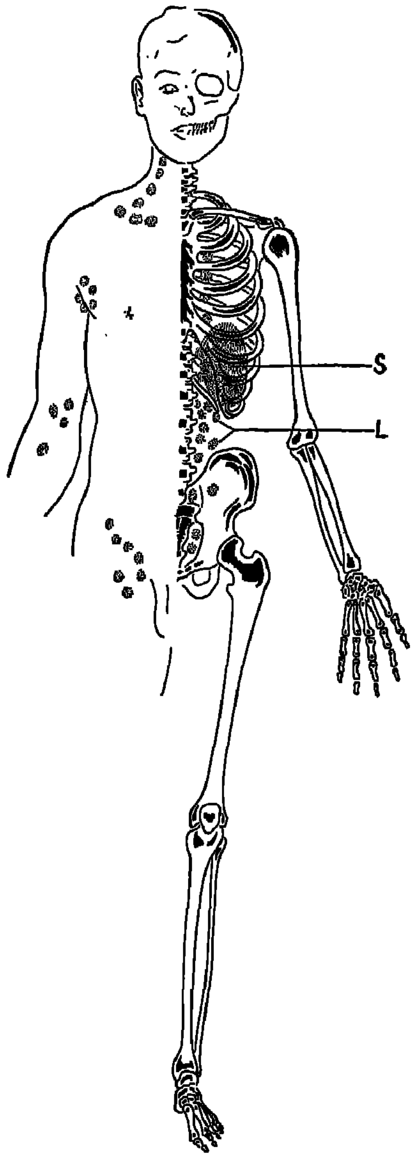


Fig. 4.1. The sites where erythrocytes and granulocytes (bone-marrow, solid black) and lymphocytes (lymph nodes and spleen, stippled areas) are produced. Left half of body shows skeleton, right upper half, soft parts.

globin the erythrocyte would be worthless. Of the many substances composing the human body, hemoglobin is one of the most interesting. If it were not for this pigment, our skins would be almost as white as paper—or a sickly putty color. Chemists have studied this material very carefully and have found out some strange things about it. They have discovered, in the first place, that it is a close relative of the coloring material of plants. The green color of plant life is due to a pigment which resembles hemoglobin. The plant pigment is called *chlorophyl*. This pigment is just as important to the plant as hemoglobin is to us. By means of chlorophyl and the sunlight, plants are able to build up starches and sugars from the water of the earth and the carbon dioxide of the air. It was also found that the brilliant colors of the feathers of some birds, the colors of their eggs, and many other hues in nature were due to pigments which resemble closely the pigment of our blood. Hemoglobin, however, is different from these pigments in one very important particular. It contains *iron*. The blood of a man contains enough iron to make a two-inch nail. As Ruskin says, "Is it not strange to find this stern and strong metal mingled so delicately in our human life that we cannot even blush without its help?"

Iron.—The iron of hemoglobin gives this pigment the power, which other similar pigments have not, to carry oxygen. We know that an iron nail soon becomes red with rust. The nail rusts because the oxygen in the air forms a chemical union with the iron of the nail. So too, the oxygen of the air in our lungs joins with the iron in the hemoglobin and turns it a brighter red. But there is an essential difference between the combination of oxygen with the iron of the nail and its union with the iron in hemoglobin. The iron rust (iron oxide) will not give up the oxygen again except under very drastic treatment.

The oxygen which combines with hemoglobin in the lungs, on the other hand, is released again with ease when the red cell reaches the capillaries. We do not say, therefore, that the hemoglobin (or the iron in it) has been *oxidized,* for that implies a firm and stable union. Instead we speak of it as being *oxygenated*. When hemoglobin loses its oxygen and becomes a darker red, it is called *reduced hemoglobin*. When the red cell is returned to the lungs and the hemoglobin takes up another load of oxygen and flashes red again, it is called *oxyhemoglobin* (see also Chap. 14).

Other constituents of hemoglobin.—Iron makes up only a small part of the hemoglobin molecule. Two other substances form its greater part—a pure pigment part called ***porphyrin*** and a protein called ***globin***. When porphyrin and iron are combined together without globin, the substance is called ***hematin***. Hematin is found in onions, spinach, cabbage, and several other vegetables, in wheat, oatmeal, yeast, meats, etc. It is apparent, then, that our bodies derive an abundance of this substance from food.

But unfortunately the hematin present in food cannot be used to any important extent by the body for the manufacture of hemoglobin. Yet provided that the diet contains adequate amounts of iron and of globin, which is present in protein foods, especially meats, the cells of the tissues have no difficulty in synthesizing the necessary amount of hemoglobin for newly formed red cells. Liver, kidney, beef muscle, and chicken gizzard are especially rich in hemoglobin-building material. Iron is usually present in adequate amounts in a liberal and well-balanced diet, but it is sometimes necessary to take additional amounts in the form of tablets or solutions. Children and women are especially likely to require extra iron.

The following scheme shows the main features in the structure of hemoglobin:

Porphyrin	found alone as the basis of many pigments in nature
+	
Iron	present in many foods (p. 245)
‖	
Hematin	found throughout the animal and vegetable kingdom
+	
Globin	present in meats
‖	
Hemoglobin	pigment of blood

The importance of hemoglobin.—Hemoglobin has the property of combining loosely with oxygen to an extent greater than any other substance known. One hundred parts of water can absorb about 0.38 parts of oxygen. The blood plasma, which is mostly water, absorbs about the same amount. One hundred parts of blood (plasma + red cells), on the other hand, absorb about 20 parts of oxygen. The blood of a man's body will absorb a liter of oxygen—

an amount which would fill a space the size of a grapefruit. An equal amount of plasma will absorb no more than could be held within a robin's egg. It is apparent, therefore, that, if the circulating fluid of the body were all plasma, its bulk would have to be some 50 times greater than it is, in order that the tissues might be supplied with the necessary amount of oxygen. The blood makes up only about one eleventh of the body's weight. If it were not for hemoglobin, the blood would have to be 2 or 3 times the weight of the solid tissues.

In the jellyfish, which possesses no hemoglobin but nevertheless requires oxygen, the fluid of its body exceeds many times the solid material. Similarly, a man, instead of needing, as he does, only about 5 quarts of blood, would need, if he had no red blood cells, some 75 gallons of circulating fluid to carry the oxygen to his tissues. In order to pump this great quantity of fluid around the body, a huge heart, having a capacity of some 2 gallons or more, would be necessary. Weighed down by his great heart and blood vessels, and swamped by a sea of body fluid, he would be left incapable of an active life. Next to oxygen itself, iron—since it is the essential part of hemoglobin—is probably the most important element in the lives of higher animals.[8]

Variations in the number of red cells. Anemia.—When the red cells are reduced in number, the condition is spoken of as *anemia.* Since the function of the red cell is to carry oxygen from the lungs to the capillaries, from where it is distributed to the cells of the tissues, persons suffering from anemia may not be able to get enough oxygen fully to satisfy their needs. They become breathless when any exertion, sometimes even the mildest, is attempted.

There are several causes of anemia—namely, *poor nutrition,* especially a lack of first-class protein food or of vitamins, or a low content of iron in the diet; *repeated hemorrhages;* and *defective function of the bone marrow.* In health red cells are produced continuously, for they have a comparatively short life (about 3 months) and the old or dead ones must be replaced by young, healthy ones from the bone marrow. A perfect balance must be struck between loss from natural causes and replacement by new cells, in order

[8] One hundred cubic centimeters of human blood contains about 15 grams of hemoglobin, and 1 gram of hemoglobin combines with 1.34 cubic centimeters of oxygen. This ratio is spoken of as its *oxygen capacity.*

that the red cell population shall remain numerically unchanged. Anemia, therefore, may arise in one of two ways: (1) either too many erythrocytes are destroyed in the circulation, or (2) as a result of the lack of the proper materials for manufacture, or because of bone marrow, too few erythrocytes are produced to replace those which disappear.

Pernicious anemia is a very severe type of blood disease due to defective function of the bone marrow. Until recent years it was invariably fatal. In this disease the liver fails to furnish a substance —the *hematinic principle*—which is essential for the normal functioning of the bone marrow. The average size of the erythrocytes is greater than normal; they are abnormal in other ways and have a short life. Thus, the number of red cells in the circulation falls to a low level[4] and, unless the disease is arrested, the patient cannot obtain a sufficient quantity of oxygen to sustain life. The usual way in which this type of anemia is now cured is by supplying the patient with the essential hematinic principle which his own liver lacks.

The discovery of this cure is an interesting story of research. A few years ago Dr. G. H. Whipple and his associates in Rochester, N. Y., found that dogs made anemic by repeated bleeding manufactured more red cells on a diet of liver than on an ordinary diet. As an outcome of these experiments, Doctors Minot and Murphy of Boston gave liberal amounts of cooked liver to patients suffering from pernicious anemia. This diet was found to increase the number of erythrocytes in a spectacular manner, to restore their normal form, and to put the patient on the road to recovery. Pernicious anemia has now been removed from the list of fatal diseases. An extract of liver which has the same curative effect as whole liver is now usually given by injection. (See Fig. 4.2.) It has been discovered recently that a factor of the vitamin B complex—*folic acid* —has a curative effect similar to that of the hematinic principle.

Hypochromic, or microcytic, anemia, a much less severe type, results from the lack of an adequate quantity of iron or of first-class protein in the diet. A deficiency of certain vitamins, especially of some factors of the B complex or of vitamin C, may also occasion-

[4] The quantity of hemoglobin in the blood of a victim of this disease may be only a quarter or less of the normal.

ally be responsible for an anemia of this type. Anemias arising in these ways are usually readily cured by correcting the nutritional fault. The erythrocytes in this form of anemia are smaller than the normal and contain less hemoglobin than in health but are not very greatly reduced in number. In pernicious anemia the cells are actually larger than normal and each cell contains more hemoglobin than do normal cells. Now, the essential defect in anemia is the reduction in the oxygen-carrying pigment hemoglobin. In

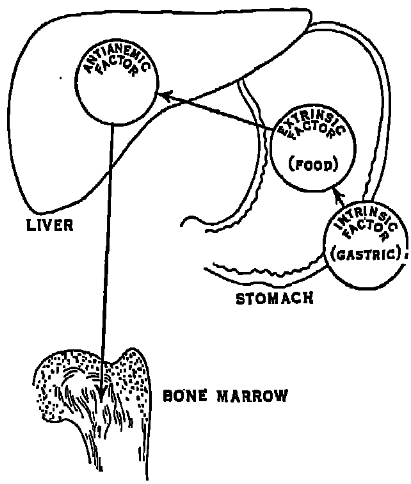


Fig. 4.2. Diagram to illustrate the normal mechanism for the production of the hematinic principle and its storage in the liver. An enzyme secreted by the stomach (*intrinsic factor*) acts upon a factor in the food (*extrinsic factor*) to form the *hematinic* (or *antianemic*) principle which acts in turn upon the red marrow of the bones.

pernicious anemia the reduction in hemoglobin is due to the reduced number of red cells (even though each cell holds more than the normal amount of hemoglobin). In the anemia resulting from a lack of iron or other dietary essential, the reduction of hemoglobin is due both to the reduction in the number of cells and to the smaller amount of hemoglobin in the individual cells. This latter type is, therefore, called *hypochromic* (Gk. *hypo* = under; *chroma* = color) or *microcytic* (Gk. *micros* = small; *kytos* = cell), whereas anemias such as pernicious anemia are called *hyperchromic* (Gk. *hyper* = above) or *macrocytic* (Gk. *macros* = large).

The number of red cells sometimes is permanently increased above the normal as a result of disease. There may be as many as 12 million or more in each cubic millimeter of blood.[5]

[5] This disease is called *polycythemia*. Its cause is unknown.

An increase in the number of red cells may occur in health. For instance, when one performs a piece of hard physical exercise, the red cells may increase by 10 or 15 percent within a few minutes; a rise in the temperature of the environment also results in an increase in the number of red cells. These increases in the red corpuscles are a result of the escape of large reserves of red cells from the spleen (p. 56). After the exercise is over, or when the air temperature falls again, the cells return to the spleen.

A visitor to a mountainous region also increases the number of his red cells very rapidly when a height of 8,000 feet or more above the sea is reached. This increase, too, is due to the discharge of red cells from the spleen into the circulation. The reduction in the oxygen of the blood not only causes contraction of the spleen but also stimulates the manufacture of red cells by the bone marrow. Thus, persons who live in the rarefied air of mountainous regions have permanently a greater number of red cells (up to 8 million per cubic millimeter) than those who live at lower altitudes. Their bone marrow is increased in amount.

The body's aim in increasing the number of red cells in the circumstances mentioned above seems clear. It has already been mentioned that the red cells give the blood its ability to carry oxygen. During muscular exercise more oxygen is required; at high altitudes the air holds less oxygen, and consequently there is less of it available for the body. In either of these instances an increase in the number of red cells will enable the blood to take up more oxygen from the air, and so to carry more to the cells of the tissues than would otherwise be possible.

Coagulation or Clotting of Blood

If a blood vessel is opened and a small amount of blood collected in a test tube, it will remain perfectly fluid for 5 or 6 minutes. After this time the tube may be turned upside down, yet the blood will not be spilled. It will have been converted into a firm red jelly. The blood is then said to have *coagulated* or *clotted*. If this blood jelly is allowed to stand for half an hour or so longer, a further change will take place. The blood will become separated into a small, firm red mass—the *clot*—and a clear, yellowish fluid—the *serum*—which surrounds it. When a portion of the clot is examined

under a powerful microscope, fine threads may be seen, forming a meshwork in which the red and white cells are held. The fine threads are composed of a protein called *fibrin* (Plate I*c* and *e*). They were formed when the blood clotted and, by their contraction afterwards, have entrapped the cells as in a net. This has caused the separation of the clot from the serum. The whole process resembles the clotting of milk. The milk first loses its fluidity; later there follows a separation into curds and whey.

We all at one time or another have had a finger pricked or cut, or a tooth pulled. Such small injuries involve the opening of tiny blood vessels and the escape of blood: But little blood is lost, for soon after the blood escapes clotting occurs in and around the opening in the vessel and the small hemorrhage ceases. If clotting did not take place, death would certainly follow. The blood would have ebbed away drop by drop, and nothing could have stopped the steady drip. If we make even a tiny puncture in a full hot-water bottle, we know that within a short time most of the water will leak out. In the same way a large part of the blood would escape from the body from the smallest wound, if blood did not clot to seal the opening.

Very complicated physical and chemical changes underlie the clotting of blood, and many years have been spent by several investigators in unraveling the intricacies of the process. The actual jellying of the blood, so obvious to the naked eye, is due to the conversion of the soluble fibrinogen of the plasma (p. 34) into the insoluble fibrin. The several processes occurring in the blood which lead up to this final change will be described as simply as possible.

Four substances—*prothrombin, calcium, thromboplastin,* and *fibrinogen*—are essential for the clotting of the blood. Should any one of these be absent, the blood remains fluid after it has been shed. The actual change in the blood when it clots is the conversion of the soluble fibrinogen to the insoluble fibrin. We have seen that fibrin appears in the form of fine threads which entangle the cells of the blood. But cells are neither necessary for nor an integral part of the clotting process. Plasma quite free from cells clots as firmly as whole blood, the only difference being that the clot is white instead of red.

The first three substances mentioned above are required to bring about the change of fibrinogen to fibrin. In the presence of calcium,

prothrombin is acted upon by thromboplastin and converted to the active enzyme called *thrombin*. Prothrombin is produced by the liver; it is present in the circulating blood but is inactive. The blood also contains calcium, but free thromboplastin is absent. Thromboplastin is contained in all the solid tissues as well as in the white blood corpuscles and platelets. When blood escapes from a vessel it is inevitable that tissue cells, platelets, or white cells are injured and thromboplastin freed. The thromboplastin then acts with the calcium upon the prothrombin, changing it to thrombin. The thrombin then acts upon the fibrinogen and converts it to fibrin. The sequence of events is summarized below:

$$\underset{\text{(inactive)}}{\text{prothrombin}} + \text{thromboplastin} + \text{calcium} = \text{thrombin}$$

$$\underset{\text{(active)}}{\text{thrombin}} + \text{fibrinogen} = \text{fibrin}$$

The blood as it flows in the blood vessels does not clot, because there is no free thromboplastin available to convert the prothrombin to thrombin. The blood glides along the smooth lining of the arteries and veins without injury to the platelets and white corpuscles. Any small amount of thromboplastin which might be produced by injury to these cells is neutralized by an antagonistic substance known as *antithrombin*, which is present in low concentration in the circulating blood. Thus, clotting within the vessels (*intravascular clotting*), which would cause instant death, is guarded against.

Intravascular clotting is easily induced in animals by injecting thromboplastin into the circulation. An extract of any tissue may be used as a source of thromboplastin, but one prepared from lung or thymus is especially rich in this material.

Anticoagulants.—Substances which prolong or prevent the coagulation of the blood are called *anticoagulants*. Among such substances are *citrates* and *oxalates*, which combine with the calcium of the blood and prevent it from acting in the clotting mechanism; *hirudin*, an extract from the mouth glands of leeches; certain *dyes; dicumarin*, a material formed in decaying clover silage; and *heparin*, produced in the livers, lungs, and other tissues of mammals.

Dicumarin and heparin are of especial interest. The first of these has been shown to be the cause of bleeding in farm animals fed

upon spoiled clover. It acts as an anticoagulant by reducing the prothrombin concentration of the blood. Heparin is a very powerful anticoagulant normally present in the body. Its function is not known with certainty, but apparently it is not produced for the purpose of preventing coagulation within the vessels, for only insignificant amounts are present in the blood. Heparin antagonizes the action of thrombin, but it is different from the antithrombin already mentioned as being present in the circulating blood.

Vitamin K and the Coagulation of the Blood.—In order to manufacture prothrombin the liver must be supplied with vitamin K. When the body lacks this vitamin the concentration of prothrombin in the blood falls to a low level and the blood clots very slowly. In such circumstances, dangerous bleeding may result from a trivial wound (p. 45). Some newborn babies bleed to death as a result of the mother's suffering from a deficiency of vitamin K.

Hemophilia.—Hemophilia is a hereditary disease in which the blood does not clot, or does so very slowly. A victim of this disease may die of a very trivial wound, for it may be impossible to staunch the bleeding. A person with this disease is known popularly as a *bleeder*. The sufferers are always boys or men. But, though the disease appears only in the male members of a family, it is transmitted to the next generation only by the females. For instance, if a father is a bleeder, neither his sons nor his daughters will have the disease. His daughters, nevertheless, but not his sons, will, when they marry, transmit it to their sons, but not to their daughters. The latter, however, will transmit it. In brief, the disease skips a generation; the grandsons of a bleeder may be affected but not his sons, daughters, or granddaughters. Color blindness and some other afflictions are inherited in an identical way (p. 348).

Bleeder Father

Son O   Daughter T

Son B   Daughter T

Son O   Daughter T   Son B   Daughter T

B = bleeder; O = not a bleeder; T = transmitter but not a bleeder.

Hemorrhage

Hemorrhage.—The escape of blood from the blood vessels, from whatever cause, is spoken of as *hemorrhage*. The blood may escape from the body, as after the infliction of an open wound which severs the blood vessels, or it may pass into the tissues and so not be visible. A *cerebral hemorrhage,* for example, is the result of a rupture of a small vessel in the brain and the spilling of blood into the brain substance. Or the bleeding may occur into one of the hollow organs, such as the stomach, in which case the blood is usually vomited, or into the intestine. Lastly, hemorrhage may occur into the lungs, and the blood may then be coughed up. When the blood appears upon the surface of any part of the body, the hemorrhage is called *external*. When the blood, after leaving the vessels, enters the tissues or one of the body cavities, we speak of *internal* or *concealed hemorrhage*.

The bleeding may be from an *artery,* from *capillaries,* or from a *vein*. When the bleeding is external, the type of vessel from which the blood escapes can usually be determined easily, since the bleeding from each kind of vessel, as a rule, shows distinctive characters —but a description of these must be postponed until the physiology of the circulation has been described (Part III).

Whatever may be the cause of the hemorrhage, the effects upon the victim of the accident are the same, provided the loss of blood from the vessels is sufficiently great and occurs rapidly. The effects are not very different whether the hemorrhage is internal or external. An animal may lose a quarter of the total amount of blood in its body and yet recover. A man would probably survive after the loss of a similar proportion of his blood.

The general effects of hemorrhage are as follows:

1. If a large quantity of blood is lost within a short time, a great drop in the blood pressure occurs. On the other hand, should the bleeding be slower, a large quantity may be lost without a sudden drop in pressure. It is easy to understand the reason for this; for we know that, if a water main should burst suddenly, the water pressure would fall very quickly, whereas a small leak in a water pipe would cause little change.

2. The breathing and pulse rates become rapid. The increase in the pulse rate is often a valuable sign of internal bleeding.

When the loss of blood is very great, the body is able to overcome to a large extent these ill effects of hemorrhage. When a vessel is opened, protective measures immediately and automatically come into play. Further hemorrhage is checked, and an endeavor is made to use to the best advantage the blood which still remains. Finally, the body strives to replace the blood which has been lost.

The means employed by the body to check hemorrhage and replace the blood.—(1) *Closure of the wound* in the vessel and the stoppage of further bleeding are brought about by the formation of a clot of blood, which seals the opening. The fall in blood pressure which occurs at this time enables the clot to form more easily. In addition, the vessel's channel becomes narrower, since the artery wall contains elastic fibers which shorten when cut. This contraction slows the flow of blood from the opened artery and allows the clot to form.

2. *The reduced quantity of blood* is used to the greatest possible advantage. The small arteries in regions of the body such as the skin, muscles, etc., which are not of vital importance, are contracted. In this way the smaller quantity of blood which remains is directed to regions such as the heart muscle and vital parts of the brain. These parts must, of course, be supplied with oxygen at all costs.

3. *Contraction of the spleen* may add a pint or more of blood to the general circulation to make up for that which has been lost.

4. *The blood vessels* draw upon the tissues to supply them with fluid in sufficient volume to replace the lost blood. Though the tissue fluid contains no red cells, it enables the vessels to be filled better, and so the blood pressure may rise again to near the normal level. The passage of fluid into the vessels from the tissues occurs within a remarkably short time after the blood has been shed. When a pint or more of blood is removed from a person for transfusion purposes, the lost fluid is replaced within an hour or two. The removal of water from the tissues accounts for the intense thirst from which the subjects of hemorrhage suffer. The tissues, including those of the mouth and salivary glands, become drier than usual. This arouses the sensation of thirst. The drinking of fluids is for this reason a valuable measure in aiding nature's efforts to restore the volume of the blood to normal.

5. *The number of red cells is restored to normal.* Since at first the blood volume is replenished to a large extent by tissue fluids, the blood is at this time poorer than normal in red cells; it is paler than usual. It may be several days or weeks, according to the recuperative powers of the individual, the amount of blood lost, diet, etc., before the number of red cells returns to normal.[6] The bone marrow increases its production and, in its haste to increase the red cell population of the blood, may in many cases turn out cells which are not quite mature. Reticulocytes and even a few nucleated cells may for this reason be found in the blood stream.

Artificial means employed for the restoration of the blood after hemorrhage.—If the amount of blood which has been shed is so great that the body is unable to meet the emergency unaided, some fluid must be injected into the patient's veins to act as a substitute for the lost blood. The fluids which may be used for this purpose are:

1. Saline solution.
2. A solution of a suitable colloid material.
3. Human serum or plasma.
4. Human blood.

1. *Saline solution* is a 0.9-percent solution of sodium chloride (ordinary salt) in sterile water. It has been used extensively in the past but has not been very successful. Its shortcomings have been recognized since World War I. The chief fault of saline is that it seeps through the thin membranous walls of the capillaries and floods the tissues. A short time after it has been injected, the blood volume is no greater than before. The molecule of sodium chloride is too small to be held back by the capillary wall. It exerts little or no osmotic pressure and, consequently, cannot retain water within the circulation.

2. *Colloidal solutions of non-human origin*—gum acacia, isinglass and gelatin, etc.—have been tried as substitutes for blood. Of course such substitutes do not carry oxygen in any important amount, since they do not contain red cells. But in many instances of hemorrhage it is not necessary to replace the red cells, for the body pos-

[6] It has been found that after 400 cubic centimeters of blood have been drawn for transfusion purposes 50 to 60 days elapse before the number of red cells returns to normal. Good food, iron, and an adequate supply of vitamins will reduce the time required for the restoration of the normal erythrocyte concentration.

sesses many more than are absolutely required to sustain life. A large quantity of blood can be removed from an animal by bleeding without causing death, provided that the blood volume can be quickly restored and the blood pressure raised to near the normal level. This can be done with a cell-free fluid having an osmotic pressure (p. 10) of nearly the same value as that of plasma. The same holds true for man. The important thing is to restore the blood volume and thus raise the blood pressure (Fig. 4.3).

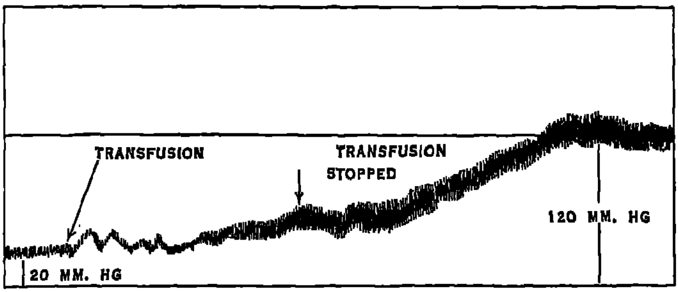


FIG. 4.3. Record of the blood pressure of a dog which was bled to the extent of 50 percent of its total blood volume and then given a transfusion with a 6-percent solution of isinglass. The blood pressure, as a result of the loss of blood, fell to the very low level of 20 mm. of mercury and the animal was on the point of death when the transfusion was started. The time from the commencement of the transfusion to the point where the blood pressure was restored to normal was about 10 minutes. (*Taylor and Moorehouse.*)

A solution, in order to be a suitable blood substitute, must not escape too freely from the circulation, as saline does. Its molecule should be as nearly as possible the size of the molecules of the plasma proteins and consequently exert nearly the same osmotic pressure. The solution should, of course, have no toxic effect and cause no rise in temperature. Isinglass, prepared from the air bladders of fish, or gelatin, which is extracted from the bones and tendons of cattle, answer these requirements most satisfactorily in so far as artificial—i.e., non-human—blood substitutes are concerned. Both of these materials are used as 5- or 6-percent solutions in saline.

3. *Human serum or plasma* from voluntary donors came into extensive use during World War II. After the blood has been drawn and allowed to clot (unless plasma is to be used), it is centrifuged to separate the serum, which is then dried in bottles under a high

vacuum. The dry mass which remains consists of the proteins and salts and requires only the addition of distilled water to make a fluid ready for use as a blood substitute. Human serum in the dry form has the great advantage that it can be shipped conveniently and does not deteriorate even after several months. The process of preparation must, of course, be carried out under the most exacting conditions in order to ensure sterility. When plasma is used, an anticoagulant is added to the blood before it is centrifuged.

4. *Human blood* is obviously the ideal fluid for the replacement of the blood which has been lost, for it furnishes erythrocytes in addition to restoring the volume of the blood. In severe hemorrhage or shock (p. 93) it is superior to any other transfusion fluid. Nevertheless, its use is accompanied by very grave danger to the patient unless special precautions are taken. This danger lies in the fact that the mixing of the bloods of different individuals sometimes causes the red cells to mass together (Plate I*d*). This is spoken of as ***agglutination***. Some of the small vessels—the capillaries—have a very fine caliber indeed. They may be so narrow that they will permit the red cells to pass along only in single file. It is easily seen, then, that if a number of cells become "glued" together into masses, they will, upon reaching these fine vessels, block them and prevent a flow of blood through the regions which the vessels supply. Occlusion of the vessels of the brain, heart, or lungs in this way may cause almost instant death.[7]

The agglutinated cells disintegrate and the hemoglobin, which escapes into the plasma, is excreted by the kidney. Being insoluble in the acid urine, it blocks the fine tubules of the kidney and thus brings urine formation to a standstill. In many, if not in most instances, this is the cause of death following the transfusion of incompatible blood.

Before the blood of one person (the donor) can be injected into the veins of another (the recipient), the bloods of the two individu-

[7] A new hazard in transfusion has been recognized within recent years. In the blood of 85 percent of persons there is a substance called the Rh factor (from its being found also in the blood of the rhesus monkey). When a patient belonging to the remaining 15 percent of the population (that is, one whose blood does not contain the Rh factor) is transfused with blood containing this factor, his blood develops within twelve days or so an anti-Rh factor. Should such a patient receive a second transfusion after this time the anti-Rh factor causes a breakdown (hemolysis) of the transfused cells and a serious, possibly a fatal, reaction may result.

als must be tested to see whether they react in the manner described above. Samples of the two bloods are diluted with saline; they are mixed together, and the mixture is examined under a microscope.[8] If the corpuscles become agglutinated, the donor's blood is unsuitable; it is termed *incompatible.* Another individual whose blood is *compatible* must then be found who will offer his blood for transfusion.

The incompatibility of two bloods may even be detected with the naked eye; for, when the bloods are mixed, the cells form groups large enough to be seen and, if agglutination has occurred, appear like grains of cayenne pepper floating upon the surface of a clear fluid. If the bloods are compatible, this does not occur, for the cells remain separate from one another and so cannot be seen by the unaided eye. The mixture remains a uniformly clear, pinkish fluid, just like any sample of diluted blood.

The bloods of all races of the world fall into four groups, according to their agglutinating reactions. The reaction relationships between the groups are rather complicated and can be touched upon only lightly. The four groups are designated, respectively, by the Roman numerals I, II, III, and IV or more usually today, by the letters O, A, B, and AB. The compatibility or incompatibility of the blood of one group with the blood of any one of the other three has been studied exhaustively and is known in a general way. Thus, the blood of group A in the great majority of instances is compatible with the blood of group AB, but is incompatible with the blood of group B. Also, group O blood is compatible with the blood of any one of the other three groups. That is to say, the blood of a person belonging to group O would not, in most cases, be agglutinated when transfused into a patient belonging to any of the other groups. For this reason members of group O have been called *universal donors.* It is never safe, however, to act upon this assumption, for exceptions occur and a dangerous if not a fatal reaction may result. Before transfusion the two bloods (donor's and recipient's) must be tested directly as described above. This so-called method of *direct matching* or *cross matching* should invariably be practiced.

[8] The most exact and safest method of testing known as *cross matching* is usually carried out. It consists in mixing the diluted blood of the donor with the serum of the recipient and then the diluted blood of the recipient with the serum of the donor.

Carbon Monoxide Poisoning

Hemoglobin combines with other gases besides oxygen. One of these is coal gas or carbon monoxide (CO), which is present as an impurity in the ordinary gas used for cooking and heating. It is also given off from the exhaust of an automobile engine. In a remarkably short time a sufficient quantity of the gas may be produced by an engine to render the air in a closed garage deadly poisonous.

This gas is worthless for living cells. If part of the hemoglobin has already combined with carbon monoxide, the pigment then cannot combine with as much oxygen. In other words, if the cargo space of the red cell is already partly occupied by the valueless gas, the cell is unable to take on a full load of oxygen. Death will result when the oxygen load is reduced below what is necessary to keep the cells alive. A victim of carbon monoxide poisoning, therefore, dies because a large proportion of his blood has been rendered useless—just as surely as if it had escaped from the body through hemorrhage.[9]

Thus, carbon monoxide is a deadly poisonous gas because it prevents the carriage of oxygen to the tissues.

There are three other facts which make carbon monoxide dangerous.

1. Hemoglobin combines much more easily with carbon monoxide than with oxygen. Should the blood be offered carbon monoxide and oxygen in equal amounts, it will combine with 250 parts of the former gas for every 1 of the latter. Consequently, though the air contains plenty of oxygen and only a small proportion of carbon monoxide, the blood loads up with the worthless gas. Carbon monoxide has no smell, taste, or color. It is therefore impossible for anyone to detect it by ordinary means.

It was the practice in coal mines and during tunneling operations in World War I to use a canary or a mouse to reveal the presence of a dangerous concentration of carbon monoxide. If the air was contaminated by this gas, the small animal would succumb long before a man would be seriously affected, and in this way warning was given of the danger.

[9] Carbon monoxide also poisons protoplasm directly bringing living processes to a standstill. But the concentration of the gas for this action is much higher than that required to cause death by combining with the hemoglobin.

2. Carbon monoxide gas, when it combines with hemoglobin, forms a compound which, unlike oxyhemoglobin, is broken down again with the greatest difficulty. That is, hemoglobin not only combines very readily with carbon monoxide but releases it again only with difficulty. Resuscitation of a victim of carbon monoxide poisoning is for this reason very difficult, even though artificial respiration is carried out in fresh air.

3. When the brain does not receive enough oxygen, the mind develops strange ideas and notions, which may lead a person to perform foolish acts or become very stubborn and unreasonable. For this reason he may remain in an atmosphere containing carbon monoxide, though he knows the danger and might easily escape. Later on paralysis of the lower part of the body may occur, and the victim is then unable to remove himself before unconsciousness supervenes.

chapter 5

THE SPLEEN. THE WHITE BLOOD CELLS OR LEUCOCYTES. THE PLATELETS

THE SPLEEN

The spleen is an organ about the size of a man's fist, lying behind and below the stomach. Its spongelike structure enables it to hold a relatively large quantity of blood—about one eighth of the total amount in the body. It is furnished with bands of muscle, which encircle it and also pass through its substance. It also contains islands of tissue of the same structure and function as that composing the lymph nodes (p. 65).

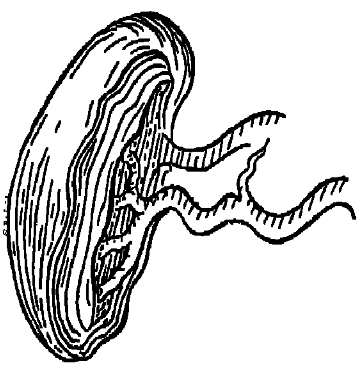


FIG. 5.1. The spleen with its vessels (splenic artery and vein).

The functions of the spleen have been touched upon incidentally in preceding paragraphs, but some additional details may be given here. The spleen contains certain very large cells known as *macrophages* (Gk. *macros* = large; *phago* = I eat). These cells are among the most interesting in the body. Unlike most other cells, they are capable of moving from place to place and apparently live an independent existence. They resemble the amoeba (p. 18); they lurk in the pools of blood which are found throughout the spongelike substance of the spleen and are able to devour worn-out erythrocytes, microorganisms, or fine par-

ticles of almost any foreign material. They are about eight times the size of a red cell, so that any red cell which has become old or has lost its vitality falls prey to them readily (Fig. 5.2). It is these cells which are responsible for the removal of the fragments of broken-down red cells from the circulation. For this reason the spleen is sometimes spoken of as the graveyard of the red cells. There is no evidence that the macrophages of the spleen can destroy young and healthy cells.

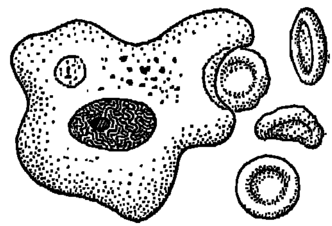


FIG. 5.2. Giant cell (macrophage) of the spleen engulfing a red cell.

The spleen also serves as a receptacle for a large quantity of blood, which has a high concentration of red cells. In times of stress or emergency, when the body requires a greater quantity of circulating blood and a greater number of erythrocytes—at high temperatures, during muscular exercise, at high altitudes, or in cases of poisoning by such gases as carbon monoxide—the muscle fibers, with which the spleen is liberally supplied, contract and force the extra blood into the general circulation, very much as fluid is squeezed from a sponge (Fig. 5.3).

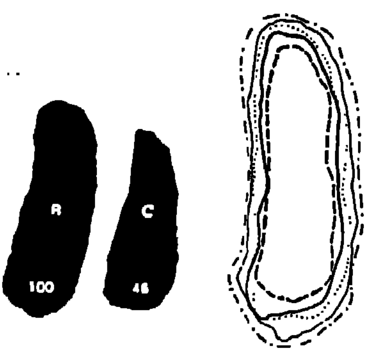


FIG. 5.3. Changes in the volume of the spleen as a result of emotional excitement. (*After Barcroft.*) *Left: R,* rest; *C,* dog sees cat. The numbers represent the relative sizes of the dog's spleen. *Right:* ——— rest; ——— smells cat; .... hears cat; —-—- sees cat; --------- chases cat.

In this way, when the body is in urgent need of oxygen, millions of red cells, each with a heavy load of oxygen, come to its assistance.

In the embryo, erythrocytes and all types of leucocytes are produced in the spleen, but after birth the spleen, in health, manufactures only lymphocytes.

The White Blood Cells or Leucocytes

The white blood cells are larger on the average than the red cells and differ from the latter in other ways. They possess a nucleus; they contain no hemoglobin; and most of them can propel themselves from place to place. The leucocytes are much less numerous than the red cells. Only about 8,000 are contained in a cubic millimeter of blood, so they are outnumbered 600 to 1 by the red cells. When a smear of blood is examined under the microscope, the white cells are seen sparsely scattered among the red cells. The different varieties of white cells are shown in Plate II*a*.

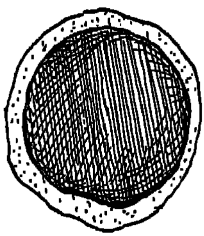


Fig. 5.4. A large lymphocyte.

There are two main types of these cells: (1) *lymphocytes*, or *agranulocytes*, and (2) *polymorphonuclears*, or *granulocytes*.

Lymphocytes have a single large nucleus surrounded by a rim of clear protoplasm (Fig. 5.4). There are two varieties—small and large. The former constitute about 25 percent of all the white cells; the latter no more than 1 percent.

Polymorphonuclears have a nucleus with two, three, or four lobes (Fig. 5.5). The nucleus resembles a skein of yarn that has been twisted and bent so as to form knobs connected by strands or threads. The polymorphonuclears also differ from the lymphocytes in that their protoplasm is speckled with fine particles or granules. They are, therefore, known also as *granulocytes*. According to the manner in which these granules take up certain dyes, three types may be recognized:

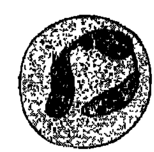


Fig. 5.5. A neutrophilic polymorphonuclear leucocyte.

1. Those containing granules which stain a violet color with neutral dyes are called *neutrophils.*

2. Those with granules which stain red with acid dyes, such as eosin, are called *eosinophils* (Plate II*a*).

3. Those with granules which stain blue with basic dyes are known as *basophils.*

The neutrophils are by far the most numerous, constituting about 65 percent of all the white cells. The eosinophils and basophils are

very few in number, the former constituting no more than 3 or 4 percent of the white cells, and the latter 0.5 percent.

The functions of the white cells.—One variety of white cell (the neutrophil) very much resembles the amoeba, which has been described on page 18. This white cell, like the microscopic animal found in ditch water, can move from place to place. It wanders about the body with perfect freedom. It is not forced to remain in the blood vessels, but can move through the joints between the cells forming the walls of the capillaries (Fig. 5.6). It can then make its way through any tissue it chooses. It sends out a little part of its

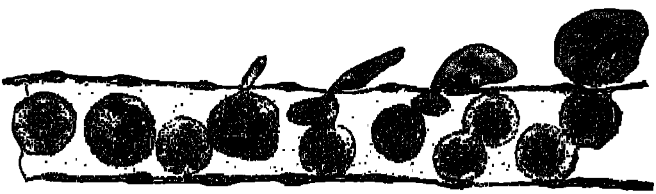


FIG. 5.6. Diapedesis. A leucocyte shown at short intervals of time during its progress through the wall of a capillary.

body which acts as a hand or foot (pseudopodium), by which it appears to pull itself along.

This white cell feeds upon particles of solid matter. But it is also attracted by small particles which can be of no possible use to it. For example, if a little charcoal is finely ground and mixed with water and then injected beneath an animal's skin, in a short time it will be found that a great swarm of white cells have been attracted to the spot. The cells can be seen moving about here and there, engulfing the charcoal until their bodies are loaded with the small black grains. This proclivity of the neutrophils makes them of the greatest value to the body. They defend it from the attacks of germs and materials injurious to the other cells, which are not nearly so well able to protect themselves.

The Russian scientist Metchnikoff discovered the action of these leucocytes about 75 years ago and wrote vivid descriptions of what he saw under the microscope when these cells were doing their work. He stuck a small rose thorn beneath the skin of a young starfish. Next day he observed that the sharp point of the rose thorn was surrounded by large numbers of leucocytes. They appeared to

be gnawing at the flesh about the irritating thorn in an effort to loosen it.

Exactly the same thing happens when a splinter runs into one's finger. The white cells rush posthaste to the spot and devour any germs which have been carried into the tissue; the splinter is loosened and falls out (Fig. 5.7). When microorganisms pass through the barrier of the skin and enter the deeper tissues, an

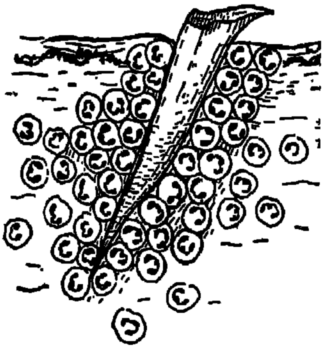


FIG. 5.7. A collection of neutrophils around a splinter embedded in the skin (diagrammatic).

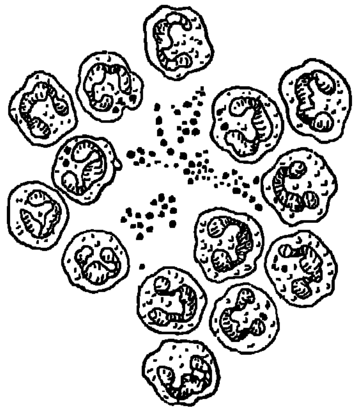


FIG. 5.8. Neutrophils surrounding a group of bacteria.

alarm in some mysterious way is sounded instantly throughout the body. Millions of white cells, which have been hidden away like troops in reserve, are quickly rushed to the threatened region. They surround the deadly bacteria and attack them (Figs. 5.8 and 5.9). Usually the invaders are devoured and killed. But many leucocytes fall victims to the bacteria's deadly poisons. The battlefield is littered with leucocytes, tissue cells, and bacteria lying dead together.

The mixture of dead leucocytes, fluids, and bacteria together form a yellowish matter, which is generally known as *pus*. The area hollowed out of the tissue and filled with this yellow matter is called an *abscess*. The number of white cells in the blood at this time may be 20,000 or 30,000, instead of the normal of 7,000 or 8,000. If it were not for the armies of leucocytes which surround an infected area, living germs would soon enter the blood; blood poisoning (*septicemia*) and very likely death would result. Life or

death is very often decided by the way in which these leucocytes do their work.[1]

Not only bacteria but also many materials which the body is better without—any useless refuse—are devoured and removed by the neutrophils. When, for instance, the tail and gills of the tadpole disappear as it develops into a frog, the neutrophylic leucocytes are responsible for the removal of these structures, which are of no further use. It is in this way also that dead tissue—even diseased

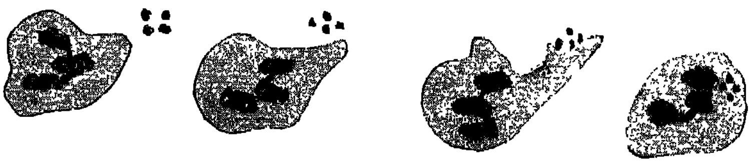


FIG. 5.9. A series of drawings of a neutrophil at half-minute intervals to show motility and phagocytosis. The dots represent a group of bacteria.

bone—is separated from the living or a dead tooth loosened. These cells, therefore, are often called the body's scavengers. Actually they serve as the tissues' first line of defense against invading bacteria. *Phagocyte* (Gk. *phago* = I eat; *kytos* = cell) is a more technical term by which these cells are known. Little is known concerning the functions of the other varieties of white cells.

All varieties of granulocytes are produced in the red bone marrow only. The lymphocytes are formed in lymphoid tissue—the lymph nodes, spleen, etc.

The Blood Platelets

The blood platelets are small colorless cells or cell-like structures[2] about half the size of a red corpuscle. They number about 250,000 per cubic millimeter of blood (Plates I*e* and II*a*). They are important elements in the blood-clotting process (p. 44). It is generally believed that the platelets are formed in the red bone marrow.

[1] Certain drugs used in medicine sometimes cause a disease known as *agranulocytosis* (meaning the absence, or great reduction in number, of granulocytes in the blood). The disease is usually fatal, because the body is unable to defend itself effectively against virulent microorganisms. Some of the drugs which cause agranulocytosis are of the greatest value in the treatment of disease, but this unfortunate action which they sometimes exert must always be borne in mind.

[2] Not all authorities are agreed concerning the precise nature of the platelets.

chapter 6

THE CONTROL OF THE REACTION OF THE BLOOD

Reaction is a term used by the chemist when referring to the acid or alkaline nature of any solution (p. 11). A solution of sodium bicarbonate (baking soda), for example, has an alkaline reaction; acetic acid (vinegar) has an acid reaction. The reaction of the blood and tissue fluids is weakly alkaline. They have a *p*H around 7.43.

We hear much these days of "an acid condition of the system," "acidosis," "acid blood," and so on. The patent-medicine advertisers speak glibly of such conditions without having any clear idea of what they are saying. It cannot be stated too definitely that the blood never becomes acid except, rarely, in certain diseases when death is only a few hours away. Even then the *p*H falls only a little below 7.00, the neutral point.

With two exceptions, no fluid or tissue of the body is ever acid in reaction. The exceptions are the lining of the healthy stomach during the secretion of gastric juice, at which time the cells of the gastric glands have an acid reaction, and the fluid leaving the tubules of the kidney. But gastric digestion and the formation of urine are very specialized processes, and in so far as reaction is concerned the stomach and kidney are in a different class from other organs. In health, the reaction of the blood remains remarkably constant at about *p*H 7.43 and only in very serious disease does it become less alkaline.

Yet acids are continuously being formed in our bodies. Carbon dioxide, which is produced in the tissues by the burning of foodstuffs, acts, when dissolved in the blood, as a weak acid (*carbonic acid*). *Lactic acid*—an acid almost the same as that found in sour

milk—is produced in the muscles when they contract, and in other active tissues. Large amounts of both carbonic and lactic acids are formed when one exercises strenuously, and smaller amounts are being formed at all times. Small amounts of hydrochloric and other acids are also produced in the body. Consequently, the blood and tissues are always being threatened with having their reaction changed to acid, but, as a result of other chemical changes which neutralize these acids immediately, no alteration of the blood reaction actually occurs.

In the first place, carbon dioxide, since it is a gas, is quickly eliminated from the body in the breath. We all know how one puffs and pants after muscular exercise. Lactic acid and other acids which cannot be got rid of as gas are neutralized in the blood and tissue fluids, both of which contain a fairly large amount of sodium bicarbonate. Any acid such as hydrochloric, tartaric, or lactic, when it comes into contact with sodium bicarbonate, is neutralized, and at the same time that neutralization occurs carbon dioxide is formed. The carbon dioxide evolved in the body by the action of acids, such as lactic, upon sodium bicarbonate, just like the carbon dioxide produced when the foodstuffs burn (p. 228), stimulates the respirations (p. 153) and is thus readily eliminated from the body.

The reaction between lactic acid and sodium bicarbonate is shown below. The neutral sodium lactate which results is removed by the kidneys. Thus

sodium bicarbonate + lactic acid = carbon dioxide + sodium lactate.
(removed by lungs) (removed by kidneys)

The kidneys remove other acids from the body as well. The blood coming to the kidneys is alkaline, but the urine, which is derived from the plasma by filtration (p. 258), is acid. The kidney retains base and excretes acid and so aids in preserving the alkaline reaction of the body fluids. This is a most important function of the kidney, which is gravely impaired in severe kidney disease.

chapter 7

THE LYMPH AND THE LYMPHATIC VESSELS

The fluid of the tissues, which, as has already been explained, is derived from the blood plasma, is collected by a system of fine canals called the *lymph vessels* or *lymphatics.* It is usual to speak of the fluid after it has entered these vessels as the *lymph.* Lymph, however, is identical with the tissue fluid. The tissue fluids and lymph are thinner than the plasma; they contain less protein, calcium, and phosphate but otherwise are practically the same in composition as plasma.

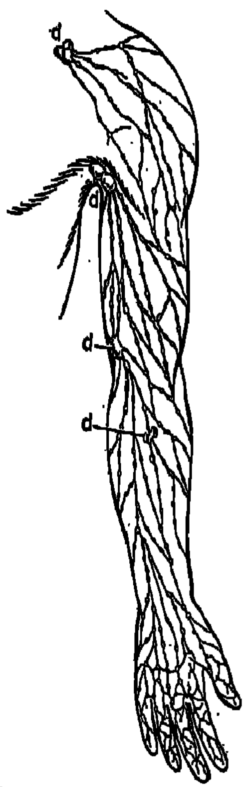


FIG. 7.1. Lymphatics of hand and arm; *d,* lymph nodes.

The lymph vessels or lymphatics.—The lymph vessels or lymphatics originate in a network of fine tubes lying beneath the skin (Fig. 7.1), among the muscles of the entire body, in the intestinal wall, and in the various organs and walls of the body cavities. The lymph vessels of the intestinal wall are called *lacteals,* because during digestion they contain a milky-looking emulsion of fat, which they have absorbed from the intestine.

Throughout the body generally the lymph vessels drain and carry away the fluid which has filtered through the walls of the capillaries into the tissue spaces. Thus, the plasma, tissue fluid, and lymph

may together be looked upon almost as one large body of fluid incompletely separated into three compartments. The fine lymph vessels in the muscles, skin, intestinal wall, and other organs join to form larger channels which ultimately pour their contents into the *thoracic duct* or into the *right lymphatic duct.* The right lymphatic duct, much the smaller vessel, drains the right side of the head and neck, the right arm, and right side of the chest. It opens into the right subclavian vein. The lymph from all other parts of the body is carried by the thoracic duct. Thus, fluid which escaped from the circulation through the capillaries and enters the lymph vessels is returned to the blood through one or other of these vessels.

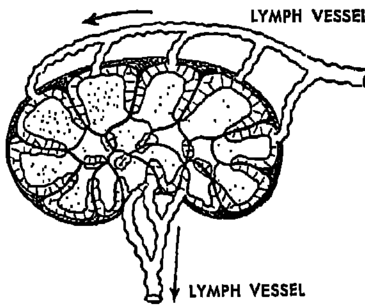


FIG. 7.2. A lymph node in cross section, diagrammatic.

Lymph nodes.—The *lymph nodes*—glandlike structures—are situated at certain strategic points in the course of the lymph vessels (Fig. 7.2). The lymph, in its course from the tissues to the point where it is returned to the blood, whether from arms, legs, abdomen, or head, must pass through these nodes, which act in a sense as sieves. Any bacteria which enter the lymph current and might otherwise be carried into the blood stream are removed. The lymph nodes in the upper part of the body are situated above the inner side of the elbow, in the armpit, behind the ear, and running down either side of the neck. Those located at the elbow and armpit drain fluid from the hand, and through those of the neck passes lymph from the tissues of the head and the throat. A pair of lymph nodes can be felt as hard, rounded objects in the groin; through them the lymph is drained from the lower limbs and crotch. When the foot becomes infected, these nodes become swollen and inflamed as a result of bacteria or poisonous materials which have reached them from the infected area. If the finger or hand becomes infected, the lymph nodes of the elbow or armpit may be similarly affected. In a septic condition of the scalp, ear, or throat the nodes at the back or side of the neck or behind the ear are involved, since they are in the path of vessels draining the lymph from these regions.

Within the nodes the bacteria are attacked by phagocytic cells (p. 59).

The lymph nodes, therefore, must be looked upon as important elements of defense against the invasion of the blood by bacteria and other injurious agents traveling by the lymphatic paths. They constitute a second defense line, the leucocytes at the actual site of infection usually bearing the first shock of the attack.

The lymph nodes and tissue of similar structure (*lymphoid tissue*) in the spleen, intestinal wall, tonsils, and other organs serve also as factories in which the lymphocytes are produced (p. 58).

part III

Circulation of the Blood

chapter 8

GENERAL PLAN OF THE CIRCULATORY SYSTEM

The circulatory system of the body resembles a municipal water system. The water system consists of a pump and a complete set of closed metal tubes or pipes. In the living circulatory system the

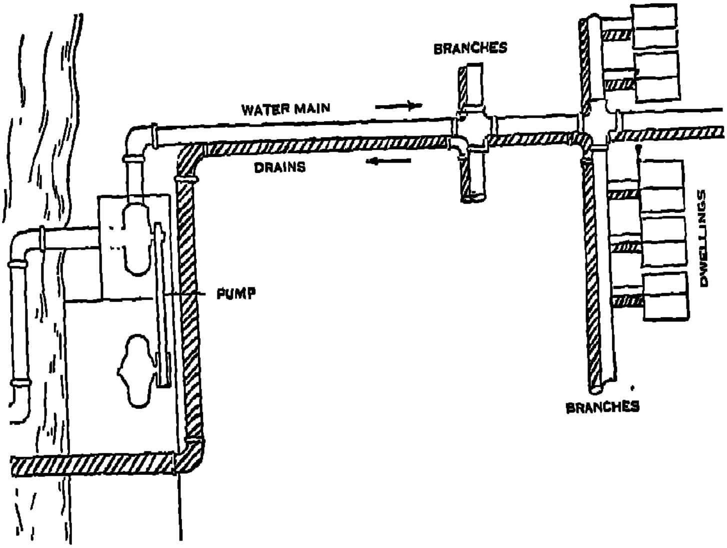


FIG. 8.1. Plan of a water system.

heart is the pump, and the closed tubes are of four kinds—*arteries, arterioles, capillaries,* and *veins* (Figs. 8.1 and 8.2). The arteries, being strong thick-walled tubes, may be compared to the large water mains of the city. The small arteries and the arterioles, into which the larger arteries divide, carry the blood from the heart to all parts of the body. The veins carry the blood back again to the heart.

The capillaries connect the arteries and the veins and conduct the blood through the tissues—muscles, skin, bone, etc. So heart and vessels form a complete circle, through which the blood flows (Plate II*b*).

It has not always been known that the blood travels in a circle. It seems so obvious to us today and is taken much as a matter of course, but for many hundred years it was universally believed that the blood simply ebbed and flowed like a tide away from and back

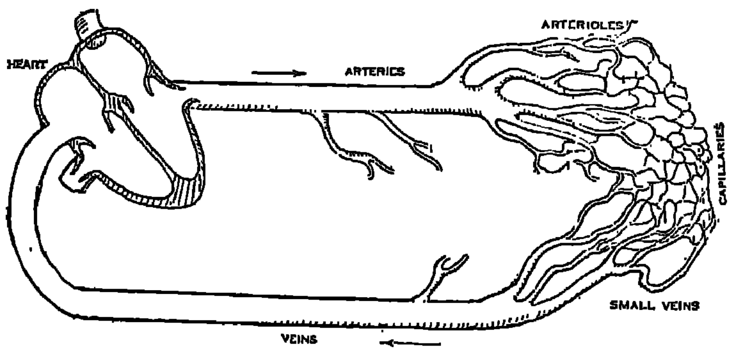


FIG. 8.2. Diagram of the circulatory system. Compare with Figure 8.1.

to the heart. The scientific world waited until, more than 300 years ago, William Harvey, an English physician, discovered that the blood made a complete circuit from the heart to the tissues through the arteries, then through the tissues, and back again to the heart through the veins (p. 77). But, though Harvey's experiments furnished the proof for this, it took half a century more for many people to accept this apparently simple fact, so firmly entrenched were the old beliefs.

The parts of the circulatory system will now be described in more detail.

The heart.—The heart is a hollow muscular organ lying with its center a little to the left of the mid-line of the chest (Fig. 8.3). The muscle of the greater part of the heart is very thick and forms thick bands, which are interlaced with one another and twisted into rings, loops, and whorls to form very strong walls (Fig. 8.4).

The heart is divided into a right and a left half by a vertical wall of muscle. Each half is again divided into an upper and lower

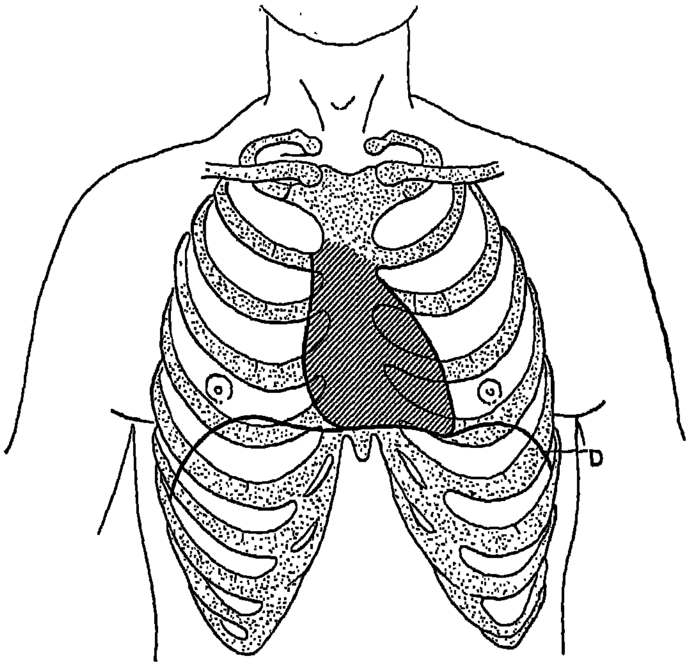


FIG. 8.3. The position of the heart in relation to the front of the chest wall. *D*, diaphragm.

FIG. 8.4. Dissection of the muscle of the ventricles of the heart to show the arrangement of the muscle fibers. (*Redrawn after Mall.*)

quarter by a horizontal partition. The upper chambers are called *auricles*—right and left. The lower ones are called *ventricles*—right and left.

The two sides of the heart are completely separated, that is, the chambers of the right side are separated from their companions on the left by the vertical wall of flesh mentioned above; but the auricle and the ventricle of the same side open into each other. This opening is guarded by valves (Plate II*b*).

The right auricle receives blood from the great veins (superior and inferior *venae cavae*), which drain the blood from the head, neck, and arms above and from the trunk and legs below. The right ventricle pumps blood *into* the lungs; the left auricle receives blood *from* the lungs; the left ventricle pumps its contents *into* the great artery or aorta. This artery gives off branches, which in turn rebranch, like the limbs and twigs of a tree, to convey the blood to all parts of the body. Thus, in reality, there are two circulations, a *greater*, or *systemic*, through the body as a whole, and a *lesser*, or *pulmonary*, through the lungs. The heart serves as a two-cylinder pump situated between and connecting the two systems.

The systemic circulation serves to carry oxygen and food materials for distribution to all parts of the body and to remove carbon dioxide and the waste products of metabolism from the tissues. The pulmonary circulation is for the purpose of "ventilating" the blood—that is, for the elimination of carbon dioxide into the air of the lungs and the absorption of oxygen.

The ventricles make up the greater part of the heart. They have thick walls, the muscle of the left ventricle being thicker than that of the right chamber, since it has more work to do. The walls of the auricles are comparatively thin. The ventricular muscle consists of numerous stout bundles which are arranged more or less concentrically so that when they contract the ventricular cavity is almost obliterated and the blood expelled (Figs. 8.4 and 9.2).

The arteries.—The arteries are comparatively large tubes which carry the blood from the heart to the most distant parts of the body. Their thick, tough, strong walls are composed of an elastic material which allows them to stretch and recoil. The largest arteries in the body are the *pulmonary*, which carries blood from the right side of the heart to the lungs, and the *aorta*, which leaves the left ventricle and, after sending branches to the head and arms, arches

downward through the thorax close against the spinal column (Plate III*a*). It sends branches to the stomach, intestines, liver, kidneys, and other organs and then divides into two large branches which go to the lower limbs. All but one of the arteries of the body carry bright red blood—that is, blood which has passed through the lungs and received a load of oxygen from the air. The one artery which does not carry bright blood is the pulmonary.

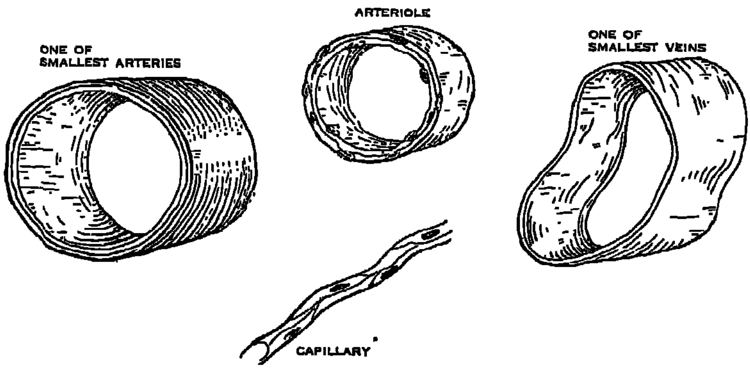


FIG. 8.5. Sections of the four types of blood vessels—arteries, arterioles, capillaries, and veins. Though the different drawings are not made accurately to scale, some idea of the actual sizes of the vessels may be gained if the reader thinks of the small artery on the left as being about the diameter of a fine needle. The largest arteries in the body—the aorta and the pulmonary —are each, in an adult, a little over 1 inch in diameter where they leave the heart.

It carries to the lungs dark blood which the heart has received from the tissues. The tissues have removed some of the oxygen from the blood as it passed through them and deprived it of its brilliant color—that is, the oxyhemoglobin has been converted to reduced hemoglobin (pp. 39 and 145).

The arterioles.—This is the name given to the very smallest tubes of the arterial system (Fig. 8.5). These vessels are little thicker than a hair (about 0.2 millimeter in outside diameter). They are different from all the other arteries in that their walls are made up of rings of muscle. These muscle fibers can contract and close off the tube, or they can relax and so make the channel of the arteriole wider. According to the comparison made above between

the circulation of the blood and a municipal water system, the arterioles represent the faucets in our houses, which can be opened or closed.

The capillaries.—The capillaries lie between the arterioles and the veins. They are the finest blood vessels in the body, being less than one tenth the width of an arteriole. Their walls have no muscle but are made of the thinnest and most delicate material—a single layer of endothelial cells (p. 22). The blood, after leaving the arterioles, must pass through the thousands upon thousands of these fine tubes in order to reach the veins. The color of our skins is due to the blood in the capillaries. When the skin becomes flushed and hot, the capillaries are filled with blood; when the skin is pale and cool, these vessels are narrower and hold less blood. When the skin is scratched, the blood which oozes from the trivial wound comes from these minutely narrow vessels. (See also p. 112.)

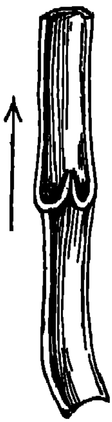


FIG. 8.6. A pair of valves in a large vein. The arrow points in the direction of the blood flow, that is, toward the heart.

The veins.—The veins are the drain pipes of the circulatory system. They collect the blood from the capillaries in the tissues and carry it to the heart. The veins near the capillaries are quite small, but by the joining together of small veins to form larger ones—like tributaries of a river—the blood, as it flows toward the heart, passes into larger and still larger vessels. The largest veins in the body are the superior vena cava and the inferior vena cava. Both of these pour the blood into the right auricle. The superior vena cava drains the blood from those parts of the body above the level of the heart—head, neck, and arms. The inferior vena cava drains the blood from those parts of the body below the level of the heart. The blood of the lungs is drained into the left auricle by the *pulmonary veins.* The blood in the pulmonary veins is bright red because it has just taken on a load of oxygen from the air in the lungs. These are the only veins in the body which contain bright red blood (see p. 144). The blood in all the other veins has given up part of its oxygen to the tissues and so is a darker red owing to the reduced hemoglobin. Anyone can see the dark color of the blood in the veins on the back of his hand or on his forearm. The

color as it shows through the skin has a bluish tint. The larger veins have valves within them, which aid the flow of blood toward the heart (Fig. 8.6).

The complete system.—In order that he may understand the two circuits of the blood—the systemic and the pulmonary—the reader should refer to Plate II*b* and read carefully the following description of a red cell's voyage.

Imagine that the cell, having been ejected by the left ventricle into the aorta, has just started upon its journey around the body. Speeding down the great artery (aorta) at the rate of a foot or two per second together with millions of its fellows, it soon reaches a branch in the vessel and may turn along it or may pass to some one or other branch beyond.

When the arteries branch into smaller twigs, many channels lie open to the cell. Whichever path it takes, sooner or later the red cell comes to a region where the channel is very narrow—so narrow, indeed, that it may brush the walls on either side or may have to be squeezed along. The corpuscle has now reached the smallest of all the blood vessels—the *capillaries.*

The stream here is flowing much more slowly than in the large arteries, and the red cell idles along at the rate of about one inch per second. Compared with the rushing arterial river which the red cell has just left, the capillary stream is an idling brook. Here also the walls of the vessels are so thin as to be transparent, and the cells of the tissues shine clearly through on either side (Plate IV*b*).

The capillary vessels are so tiny, indeed, that ten or more could be laid side by side upon a hair. Yet, if we were to take the cross sections of all these delicate tubes in all the tissues of the body and add them together, we should find that the sum was 500 to 1,000 times greater than the cross section of the one large artery—the aorta—by which the blood left the heart. In other words, the bed of the stream over which the blood flows has become tremendously expanded in the region of the capillaries. It is as though a swiftly moving river had flooded a tract of marshy ground furrowed by innumerable channels. This explains the slowness of the stream in the capillary region.

The red cell, having journeyed through the capillary, enters somewhat larger vessels again—the *small veins* or *venules.* As it reaches

larger and larger venous tributaries its speed increases; soon it is carried into one or other of the great veins (superior or inferior vena cava) and enters the right auricle of the heart. The speed of the red cell in the large vein where it opens into the right auricle is not much less than the speed of the blood in the aorta. Having reached the right auricle, it has now made a complete round of

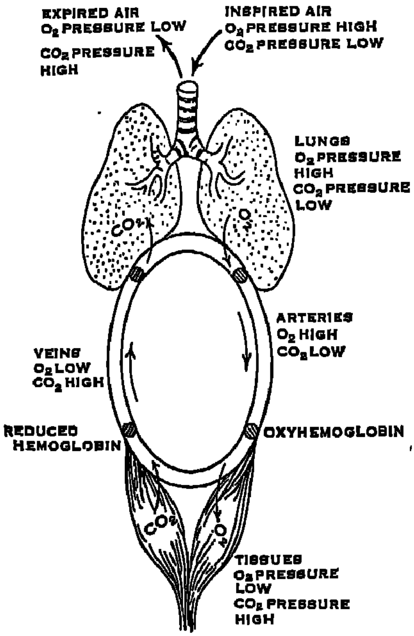


FIG. 8.7. Schematic diagram to show the exchange of the respiratory gases—carbon dioxide and oxygen. For the sake of simplicity the pulmonary and systemic circuits are combined into one circle and the heart omitted.

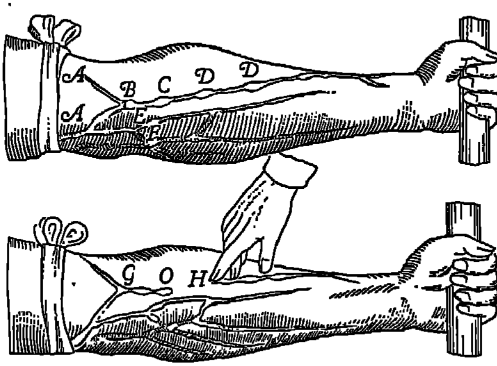
the systemic, or greater, circulation. In its slow passage through the capillaries it has given up to the tissues a part of the oxygen load with which it entered the aorta. So, by the time it has returned to the heart, the red cell has lost its scarlet color and is a darker red (Fig. 8.7).

After entering the right ventricle, it is ejected into the large pulmonary artery and so enters the pulmonary, or lesser, circulation. In the lungs it passes through capillaries again. There it becomes exposed to the air which has been breathed in and takes on a load of oxygen. Leaving the capillaries as before, it enters a small vein and then successively larger veins, to reach the left auricle through

one of the large *pulmonary veins.* Finally, the left ventricle receives it, and the red cell has returned to the point from which it started half a minute or so ago—for that is about the time the red cell takes to make a tour of both circulatory systems.

Emphasis should be laid upon certain points in the foregoing account. The right side of the heart contains only venous blood—that is, blood which has passed through the capillaries of the systemic circulation and so has given up part of its load of oxygen to the tissues. A third of its hemoglobin is in the reduced state (p. 145).

FIG. 8.8. Illustration of an experiment of William Harvey from his great work published in 1628, *De motu cordis et sanguinis* (the movement of the heart and blood). When a vein was compressed by the finger it collapsed on the side toward the heart and became distended with blood on the other side.



The left side of the heart contains only arterial blood or blood *which has passed through the capillaries of the lungs and taken up* nearly a full load of oxygen. Fully 95 percent of its hemoglobin is oxygenated (oxyhemoglobin). It has already been said that arteries carry blood away from, and veins carry blood to, the heart. The pulmonary artery, which conveys blood from the right ventricle to the lungs, and the pulmonary veins, which carry blood from the lungs to the left auricle, are therefore correctly named. Nevertheless in one particular the pulmonary artery resembles a vein—it contains reduced, or so-called venous, blood. The pulmonary veins, on the other hand, contain oxygenated or arterial blood, and in this they resemble arteries. These are the only exceptions to the rule that an artery contains oxygenated and a vein reduced blood.

William Harvey and the discovery of the circulation of the blood. —By a series of simple experiments William Harvey (1578-1657) showed that the blood must take the course just described. He

pointed out that the valves of the heart were so fashioned that the blood could go in only one direction; that there could be no to-and-fro movement as was supposed by the medical men of his time. He saw that when in the living animal the pulmonary veins were tied no blood entered the left ventricle; when the pulmonary artery was similarly obstructed, no blood passed through the lungs. Thus, he proved that the blood was driven from the right to the left ventricle, i.e., through the pulmonary circuit.

The course of the blood through the systemic circulation was deduced from the following experiments. Compression of the aorta was followed by damming of blood in the left ventricle, which became dilated and labored in its beat. When, on the other hand, the great veins entering the right auricle (superior and inferior venae cavae) were tied, the right chambers of the heart collapsed, since they received no blood. When a large superficial vein was compressed (Fig. 8.8) it became swollen with blood on the side of the obstruction farther from the heart and empty on the near side; compression of an artery caused the pulse to disappear in that part of the artery beyond the point of pressure. Undoubtedly then, Harvey argued, the blood must be carried from the heart in the arteries and toward the heart in the veins.

chapter 9

THE ACTION OF THE HEART

The heart is a highly efficient pump. For its size it is capable of performing an almost incredible amount of work. It is also able automatically to adjust its performance to the amount of work which it is required to do. A powerful man doing heavy work or running a race may pump from his heart 8 gallons of blood in a minute. It would take about four ordinary water buckets to hold that amount of blood, and it would take more than a minute to fill them from a hand pump many times larger than the heart. Moreover, this great quantity of blood is thrown from the heart against a high pressure. If we could tap the great artery—the aorta —and allow the blood to escape into a straight vertical pipe between 5 and 6 feet high, the blood would be forced to the top.

The heart valves.—A pump, in order to drive fluid through a system of tubes, must be able to raise a pressure within its cylinder and must possess valves so that no energy is wasted by forcing the fluid in a wrong direction (Fig. 8.2 and Plate II*b*). The valves of the heart are thin membranous leaves, placed at the openings from auricles to ventricles and at the openings of the aorta and the pulmonary artery (Fig. 9.1). They are opened and closed by the pressure of blood on one or the other of their surfaces. The heart pump has two "cylinders"—the ventricles—both of which are emptied at each stroke. The power is derived from the contraction of muscular tissue, which, as we have seen, composes the heart's walls.

Each set of valves will open in one direction only. Those between each auricle and ventricle open downward into the ventricle when the pressure of blood in the auricle is great enough to force them apart, but they cannot be made to open upward into the auricle,

no matter how high the pressure may rise later in the ventricle when it contracts.

Cords or tendons, like the lines of a parachute, run from the delicate valve leaflets to fleshy pillars (*papillary muscles*) which

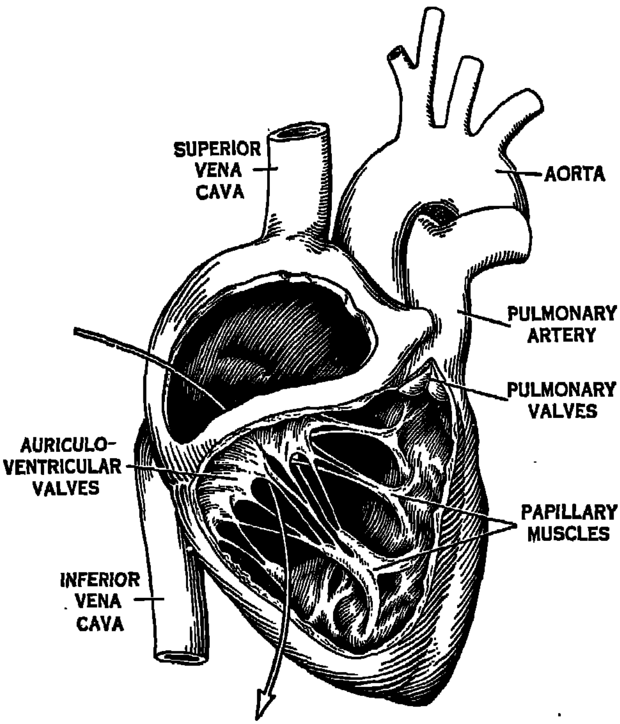


FIG. 9.1. The right side of the heart with the wall of the auricle and ventricle cut away to show the pulmonary and right auriculo-ventricular valves, the papillary muscles, and cords running from these to the valve leaves. The arrow passes through the opening between auricle and ventricle.

arise from the walls of the ventricles. These cords prevent the valves from being forced upward into the auricle when the ventricle contracts (Fig. 9.1). When the contraction occurs, the pressure within the cavity of the ventricle rises, and the valves between the auricle and ventricle are closed. As the pressure mounts still higher, the valves at the openings of the arteries (pulmonary and aorta) are forced open, and the blood rushes into these great arterial mains. When the ventricles relax again, and the pressure within these

chambers falls below what it is in the great arteries, the valves close again. The pressure in the ventricles continues to fall for a while and, when it falls below the pressure in the auricles, the valves in the floor of these chambers open and allow blood again to fill the ventricles.

The filling of the ventricles, the closure of one pair of valves followed by the opening of the other pair, the outrush of blood from the ventricles, and finally the relaxation and refilling of the ventricle are repeated again and again with perfect regularity 70 times each minute.

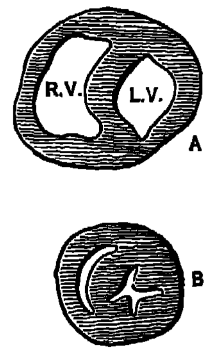


Fig. 9.2. Ventricles cut across, *A*, during diastole; *B*, during systole. *R.V.*, right ventricle; *L.V.*, left ventricle. (*After Ludwig.*)

The heart is the most industrious and indefatigable worker of the body. At every beat the left ventricle of a man at rest exerts a force sufficient to lift a weight of over 2 ounces to a height of nearly 6 feet. Each hour it does an amount of work equivalent to raising a weight of 500 pounds to the same height. The work performed in 24 hours by the left ventricle alone of a man lying quietly in bed equals that required to raise the weight of his body to the top of a 40-story building.

During strenuous muscular exercise, the heart's work is increased many times, for it not only pumps out more blood per minute but does so under a higher pressure. The quantity of blood which the heart pumps into the arteries each minute is called the *cardiac output* or the *minute volume of the heart.* A healthy man can increase his cardiac output from around 4 quarts per minute during rest to as much as 35 quarts during very strenuous exercise. In order for the heart to perform this amount of work the flow of blood through its own arteries (*coronary arteries*) must be increased enormously to furnish its muscle with the necessary quantity of oxygen (p. 114).

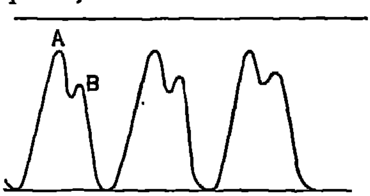


Fig. 9.3. A record of the pulse wave; *A*, crest due to the sharp expansion of the artery by blood discharged by heart; *B*, secondary wavelet known as the dicrotic wave.

The cardiac cycle or beat.—The series of different actions which the heart performs in succession is spoken of as its *cycle* or *beat.* Starting with any one of the separate actions or movements of the heart, the series of changes which takes place until that particular action commences to repeat itself constitutes a *cardiac cycle.* The contraction of the heart is called *systole;* its relaxation is called *diastole* (Fig. 9.2). A comparison between the heart muscle and a skeletal muscle may be drawn to show these two phases of the cardiac cycle. If the reader will grasp the biceps of one arm with

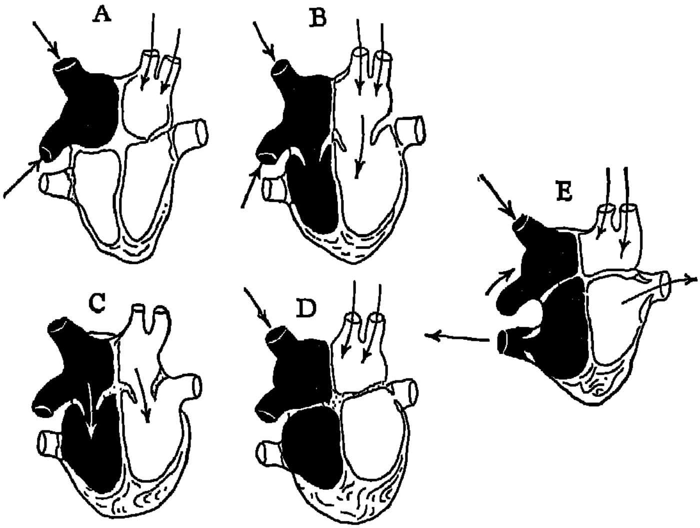


FIG. 9.4. Diagram to show different phases of the cardiac cycle. *A.* Auricles filling, valves between auricles and ventricles closed, ventricle relaxed, valves at arterial openings closed. *B.* The valves between the auricles and ventricles have opened, and blood is pouring into the ventricles which are still relaxed. *C.* The auricles contract and empty into the ventricles which are filled to capacity. *D.* The ventricles contract and close the opening into the auricles. The pressure then rises rapidly and when sufficiently high to overcome the pressure in the pulmonary artery (or the aorta in the case of the left ventricle) the valves guarding the orifice of the artery open. In this sketch the valves are still closed; the ventricle is therefore a completely closed cavity. *E.* The arterial valves have been forced open and the blood is now being forced into the pulmonary system (or aorta). The left side of the heart is drawn as though empty in order to show more clearly the positions of the valves, but it must be remembered that whatever is occurring on the right side of the heart is occurring at the same instant on the left side.

the opposite hand and alternately bend (flex) and unbend (extend) his elbow he will feel the muscle become firm and round when it contracts and flat and soft when it relaxes. Though the biceps is solid, not hollow like the heart, its contraction corresponds to the systole of the ventricle and its relaxation to the diastole.

In order to follow the successive acts performed by the heart, let us start at that moment when the ventricle is relaxed (diastole) (Fig. 9.4*A*), that is, at the end of the ventricular contraction (systole), at the moment when the valves at the openings of the arteries have just closed and the valves between auricles and ventricles have not yet opened. The blood at this time pours into the auricles; a fraction of a second later the valves between auricles and ventricles open, and the blood streams into the ventricles (Fig. 9.4*B*). Soon the ventricles are filled or nearly filled. The auricles at this moment contract to give an extra spurt to the blood and practically empty themselves into the ventricles (Fig. 9.4*C*). As though at a signal, the ventricles contract. At once the valves of the auricles close, but the valves of the great arteries have not yet opened. The muscles of the ventricles continue to contract, and press upon the mass of blood in the ventricles. The pressure within the ventricles rises to a great height—a pressure sufficient to support a column of mercury 5 inches (120 millimeters) high, or to throw a stream of blood or water to a height of 6 feet or more. The valves guarding the arteries are forced open, and a flood of blood pours along the aorta and all the arterial channels (Figs. 9.4*D* and *E*). After their brief contraction the ventricles relax again; then the pressure within their cavities falls, the higher pressure in the arteries closes the arterial valves (at aortic and pulmonary openings), and this cycle comes to an end. Another cycle begins immediately.

The Pulse

Each beat of the heart causes a pulse in the arteries which can be felt as a light tap or impact if one presses a finger lightly over any large artery. The most usual place to feel for the pulse is over the radial artery at the wrist. But it must not be thought that the radial is different from any other artery in so far as the pulse is concerned. It is usually chosen simply because it is conveniently

situated. The heart rate, and therefore the pulse rate, of a man at rest mentally and physically is about 70 per minute. When hard work is done the pulse quickens, and in very strenuous exercise it may rise to 180 per minute. Emotion and excitement also cause an increase in the pulse rate. In ill health fever is the most common cause of rapid pulse.

It is a general rule that the smaller the animal the more rapid is its heart rate—that is, the shorter is the heart's cycle. An elephant's

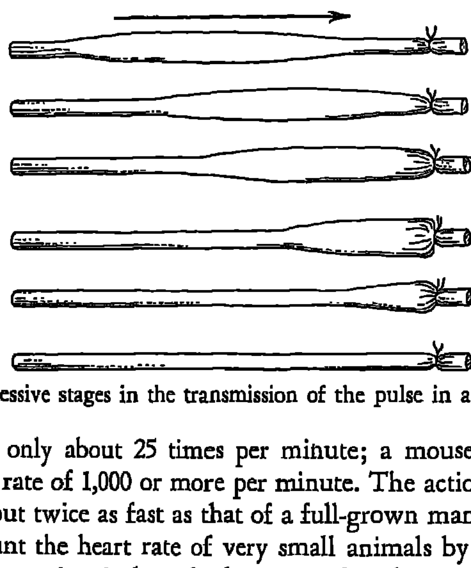


FIG. 9.5. Successive stages in the transmission of the pulse in a ligated artery.

heart beats only about 25 times per minute; a mouse or a canary has a heart rate of 1,000 or more per minute. The action of a baby's heart is about twice as fast as that of a full-grown man. It is impossible to count the heart rate of very small animals by the ordinary means. Special electrical methods are employed to record it.

Some persons misunderstand the nature of the pulse because they think that the beat is caused by the flow of the blood in the radial artery. The pulse is actually a wave set up in the walls of the vessels, and the blood contained within them, by the systole of the ventricle. The nature of the pulse may be made clear by means of an illustration. If an elastic band be stretched between two rigid supports and struck lightly or plucked at one end, a coarse vibration of wave travels to the opposite end. The impact upon the wall of the aorta by the blood discharged from the ventricle travels through the walls of the arterial system in a similar manner. The highly elastic wall of the aorta is expanded by the contents of the ventricle but immediately recoils again. Thus, a wave of expansion and recoil

—a wave with a high- and a low-pressure phase—is set up and transmitted at high velocity even to the smallest arteries (Fig. 9.3).

The more elastic the walls of the vessels, the more slowly does the pulse wave travel. The speed of the wave is, therefore, considerably greater in an old person than in a child, because the arterial walls become stiffer and harder and consequently less elastic with advancing years.

The speed of the pulse wave is quite independent of the speed of the blood itself. We can demonstrate the fact by tying off a large artery. The blood in the vessel is brought to a standstill, yet the pulse is not abolished and its speed is not at all reduced (Fig. 9.5).

The Apex Beat and the Heart Sounds

The heart muscle becomes harder and more rounded in form when it contracts. During systole it bulges forward, rotates a little to the right, and presses against the chest wall between the fifth and sixth ribs, at a point a little to the right and below the left nipple. A slight, soundless tap caused by the heart as it touches the chest wall can be felt in this spot with the fingers placed flat against the skin. It is called the *apex beat.*

The sounds which are heard when the ear is pressed against a person's chest, or when a special instrument known as a stethoscope is employed, are made within the heart itself. There are two sounds heard in quick succession; a slight pause follows, and then they are repeated. The sounds resemble the syllables "lub" and "dup," for the first sound lasts longer, is softer, and has a deeper pitch (like "lub"), and the second sound is short, sharp, and of higher pitch (like "dup"). The first sound ("lub") is composed of two sounds blended together. These are (1) the vibrations set up by the contraction of the heart's muscle, and (2) the vibrations caused by the valves between the auricles and ventricles closing and their leaflets being put under tension by the pressure created in the ventricles at the commencement of systole. The second sound ("dup") is purely valvular in origin; that is, it is due to the closure of the valves at the openings of the pulmonary artery and the aorta.

So long as the valves come together tightly and accurately, no blood can leak through in the wrong direction, and the heart performs its work with the efficiency of a good pump. Disease, how-

ever, not uncommonly attacks one or more sets of valves, causing them to become deformed, stiff, or partly destroyed. The affected valve may then be unable to close as tightly as it should in order to prevent the leakage of blood. Or it may not open freely, and so offer an impediment to the flow of blood through the opening which it is supposed to guard. In either instance, the heart does its work less efficiently.

A heart with a defective valve is at a mechanical disadvantage; it must do more work than the healthy heart in order to maintain the circulation in any circumstances, but especially during muscular exercise. Its muscle becomes thicker, or *hypertrophied*, and its cavity *dilated*. These changes enable the heart in most instances to compensate for its handicap, and, provided that the heart muscle itself does not fail, good health may be enjoyed for years by one whose heart has a valvular defect. Exercise even of a severe nature will not injure a healthy heart, but it may be dangerous for a person with a diseased heart valve to undertake strenuous muscular work.

When a set of valves is diseased, the clear sound caused by the closure of healthy valves is no longer heard. There is heard, instead, a rushing or swishing sound, resulting from the leakage backwards of the blood, or from the obstruction of the flow of blood through the opening. The physician, by listening to the beats of the heart, can easily detect these unusual sounds, which are called heart *murmurs*. In this way he can tell which valve is diseased and can determine the condition of the heart. Rheumatic fever and certain infectious diseases, particularly scarlet fever, are commonly responsible for diseases of the heart valves.

chapter 10

THE ARTERIAL BLOOD PRESSURE

William Harvey proved that the blood made a circuit through the body—that it was ejected from the left ventricle into the arteries and returned to the right side of the heart by the veins. Yet he did not know that the blood circulated at a high pressure—or, if he held any opinion upon the matter, he made no comment. He probably thought, with the men of his day, that the blood currents were somewhat sluggish streams—that the flow through the arteries resembled the flow of water through canals or drains rather than the swift rush of fluid through closed pipes.

An English clergyman, the Rev. Stephen Hales, in 1733 was the first to demonstrate the high pressure of the blood in the arteries. He inserted a small brass tube into a large artery of a horse and connected the small tube to an 8-foot glass tube placed in a vertical position. When the clamp was removed from the artery, the blood rushed into the tube and rose nearly to the top. The top of the column of blood was observed to fluctuate up and down at each beat of the heart.

Since Hales' day much more convenient methods of taking the blood pressure have been devised. Instead of a long empty tube, a small tube, bent into the form of a U with the bend filled with mercury, is now employed (Fig. 10.1). This instrument is called a *manometer*. The blood presses upon and raises the mercury, which, being some 13½ times heavier than blood, rises only a few inches instead of several feet. For this reason it is customary to express the amount of the blood pressure in terms of the height, in millimeters of the column of mercury (abbreviated as mm. Hg[1]) which it will

[1] Hg is the symbol for *Hydrargyrum*, mercury.

support. Thus we speak of the blood as having a pressure of 120 or 150 mm. Hg, as the case may be. There were no anesthetics in Hales' day, and so the animal must have suffered pain. Today whenever it is necessary to demonstrate directly the blood pressure

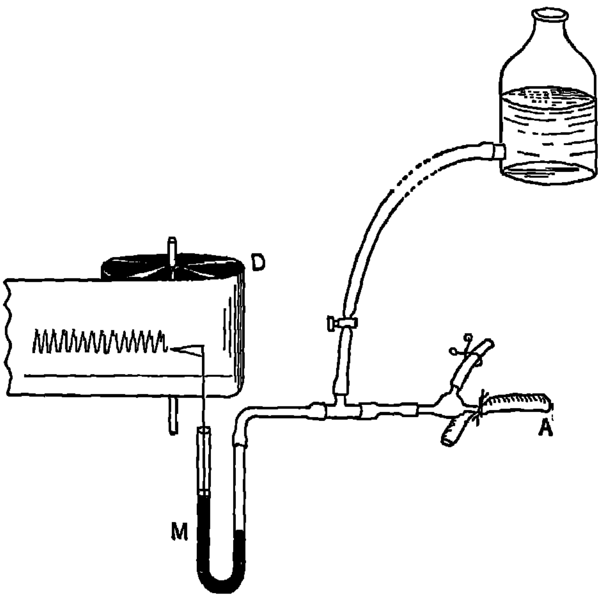


FIG. 10.1. The method of recording the blood pressure in animals. *A,* section of the artery with a glass connecting tube (canula) inserted. *D,* revolving drum (kymograph) covered with smoked paper. *M,* mercurial manometer. The reservoir bottle supplies an anti-coagulant fluid under the desired pressure.

in an animal, an anesthetic is always used, and no pain is ever occasioned.

Systolic and diastolic pressures.—When the aortic valves are open and the ventricle contracts and forces blood into the arteries, it is apparent that the pressure in the arteries must reach its highest point. When, on the other hand, the heart relaxes and the aortic valves close, the pressure must decline again. Just before the next contraction of the heart occurs, the arterial pressure must reach its lowest level. Since the heart's contraction is called systole and its relaxation diastole (p. 82) the highest point of pressure in the arteries is termed the *systolic pressure,* and the lowest point is called

the *diastolic pressure*. The *mean pressure* is the term applied to the average of these two (Fig. 10.2). Thus the normal systolic pressure in man is about 120 mm. Hg; the diastolic, 80 mm. Hg; and the mean pressure, 100 mm. Hg. The blood pressure in a small animal, such as a rat, a cat, or a dog, is not lower than in man. The systolic blood pressure of a rat is around 120 mm. Hg, and that of a dog is actually higher than the human. Probably the blood pressures of an elephant and a mouse are not greatly different.

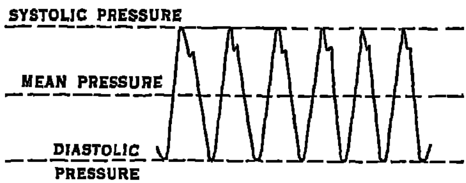


FIG. 10.2. The phases of the arterial blood pressure.

HOW THE BLOOD PRESSURE IS CREATED AND MAINTAINED

Practically every part of the body must receive a regular supply of oxygen, or the cells which compose it will very soon deteriorate and finally die. To deliver this supply of oxygen, blood must be moved swiftly and under sufficient pressure so that it may be forced into the most distant regions of the body. If the blood pressure falls below a certain level, the tissues will be supplied with blood very poorly, or not at all. The brain will no longer carry out its functions; unconsciousness, ending in death, will result. It is important, then, to inquire into the means by which the stream of blood is kept at the necessary pressure.

In order to understand the factors upon which the arterial pressure depends, let us return to the comparison which was made on page 69 between the circulation and a municipal water system. The complete water system which serves the houses of a city consists in reality of two divisions. These are the pump and the large water mains, on the one hand, and the drains, on the other (Figs. 8.1 and 8.2). Between these two divisions are a large number of separate faucets. When a faucet is opened, water flows out and is collected and carried away by drain pipes, which in many cities empty their contents into the same body of water from which the

pump is fed. In the water mains the pressure is many times greater than in the drains.

The circulation of the body is also divisible into an arterial or high pressure system and a low pressure system—the capillaries and veins. The pressure in the latter vessels is only a fraction of that in the arteries. Between the two systems a number of small arteries are situated, which at one time may open widely, and at another time may be tightly closed. These vessels, called *arterioles*, have been spoken of already on page 73. The walls of these fine tubes are composed of muscle fibers, which run circularly around

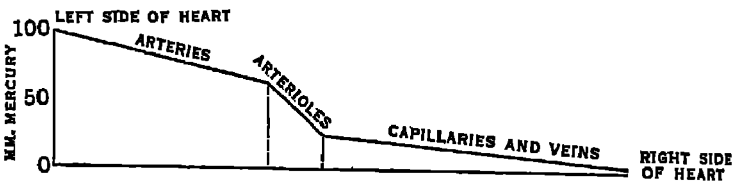


FIG. 10.3. A graph of the arterial blood pressure throughout the circulation. Note the very low pressure of blood entering the right auricle and the sharp drop in pressure in the region of the arterioles.

them. When these muscular rings contract, the caliber of the vessel is reduced, less blood can flow through it, and we say the vessel has *constricted* (p. 107). When the muscle relaxes, the caliber of the tube becomes larger, more blood escapes into the capillaries, and we say the vessel has *dilated*. The arterioles therefore correspond to the faucets in the water system. Figure 10.3 shows the fall in pressure which occurs in the circulatory system from the left to the right side of the heart.

The following factors are responsible for maintaining the arterial blood pressure:

1. Pumping action of the heart.
2. The peripheral resistance.
3. The viscosity of the blood.
4. The quantity of blood in the arterial system.
5. The elasticity of the arterial walls.

We shall say a few words about the role played by each.

The pumping action of the heart.—The arterial pressure will be raised if the quantity of blood which the heart discharges into the arteries each minute (cardiac output) is increased. This is obvious;

since the arteries will contain more blood, the blood will distend their walls more fully. Should the pump expel less blood in a given time, the pressure will fall. These statements, however, hold true only provided the four other factors mentioned above remain unchanged. Like any other pump, the heart may increase the quantity of fluid discharged during any period by increasing the quantity which it expels at each beat, while the number of beats per minute remains the same; or it may increase the discharge by beating more frequently, while the quantity of blood discharged at each beat remains the same. Again, it may increase both the rate of its beat and the quantity discharged at each beat.

The peripheral resistance.—This time-honored term is applied to the resistance which the great number of small arterioles offer to the flow of blood out of the arterial system into the capillaries and veins. We all know that it is more difficult to drive fluid along a narrow tube than along a wide one, because there is more friction. It has already been mentioned that the arterioles can, since they have muscles in their walls, be constricted or dilated. The resistance to the flow of blood will be greater and less blood will therefore pass in any given time from the arterial system when the arterioles are constricted than when they are dilated. Just as the pressure in a town's water system would drop if the faucets in all the houses were opened at the same time and more water allowed to flow into the sinks and drains, so, when the arterioles are dilated and more blood streams into the capillaries and veins, the arterial pressure falls; when the arterioles are narrowed, the pressure rises.

The viscosity of the blood.—Perhaps the simplest way to define the term *viscosity* is to say that it refers to the thickness or stickiness of a fluid. Fluids such as sirup and molasses are many times more viscous than water; blood is five time more so. A viscous fluid flows more slowly along a tube than other fluids, and more force is required to drive it through, since more friction is developed between its molecules. If two syringes are filled, one with water and the other with a heavy oil, it will be found that a very much greater force must be exerted upon the plunger, and a greater pressure must be created in the barrel of the syringe, to force out the oil than to drive the water from the syringe nozzle. The oil has a higher viscosity than the water. In the same way, the viscosity of blood, being higher than that of water, aids in keeping the blood pressure

at the usual level; the blood flows less freely through the fine arterioles than would water or saline.

The quantity of blood in the arterial system.—It is quite apparent that any pressure system must contain a sufficient amount of fluid to fill its channels before any degree of pressure can be developed. The walls of the arteries can be stretched, so in reality the system can be over-filled. The more blood, therefore, that is contained in the arteries and the more their walls are stretched, the greater will the pressure be. If blood is lost by hemorrhage, the pressure will fall; fluid injected into the circulation causes the pressure to rise (see p. 50).

The elasticity of the arterial walls.—The arteries are composed of elastic tissue. In ordinary circumstances these vessels are over-filled with blood, and their walls are slightly stretched at all times. At each beat of the heart an extra amount of blood is discharged from the ventricle, and the walls are stretched still further. When the heart pauses again—that is, during its diastole—the stretched walls of the arteries recoil again, like an elastic band which has been released from a stretching force. When the walls recoil in this way, they press upon the blood and force it onward through the arterioles during the pause of the heart. As a consequence, the flow of blood into the capillaries and veins is continuous, and not in squirts. The capillaries and veins, then, unlike the arteries, do not pulsate. In a water system the pipes are made of non-elastic, rigid material, but we know that, though the water is forced into the system by a pump which works intermittently like the heart, the water flows from the faucets in a continuous stream, not in jets. This effect is obtained either by pumping the water up to a reservoir situated at a considerable height, from which it flows steadily by gravity to the faucets, or by employing a standpipe. This device serves a purpose corresponding to that served by the elastic walls of the arterial system. The standpipe is a large vertical pipe, closed at its upper end and filled with air. When the water system is filled the air is driven upwards by the rising water and compressed in the closed upper end of the pipe. The trapped air acts as an elastic buffer, against which the water is forced at each beat. The pneumatic cushion serves to keep up the pressure between beats of the pump. During each beat of the pump water rises a little in the pipe and

compresses the air; between beats the air expands again and in so doing forces the water along the pipes to the faucets; thus the pressure is never allowed to fall to zero.

To summarize—the elasticity of the vessel walls prevents the pressure from falling too low between the beats of the heart. That is to say, it is responsible for the diastolic pressure and for converting the pulsatile or throbbing flow in the arteries into a continuous flow in the capillaries and veins.

Changes in the blood pressure levels.—When strenuous muscular exercise is undertaken, the arterial pressure rises much higher than the values given on p. 89. The systolic pressure in a man running a short race, for instance, may rise to 170 or 180 mm. Hg or more. Excitement, emotions, or certain substances, such as alcohol, adrenalin (p. 425), etc., may also cause the pressure to rise above the usual level. On the other hand, certain conditions may cause the pressure to fall lower than it should be. Hemorrhage, weakening diseases, surgical shock, or anesthetics may cause a pronounced fall in blood pressure.

There is a disease known simply as "high blood pressure" (or *hypertension*), in which the arterial pressure is always very high. The systolic pressure remains permanently at a level, in extreme cases, of 300 mm. Hg or more, and the diastolic may be over 150 mm.[2] If it were possible to place a long glass tube in the artery of such a person, as Stephen Hales did in the artery of a horse, the blood would rise to a height of more than 12 feet instead of between 5 and 6 feet as it would in a healthy man.

It is not known with certainty just what causes hypertension, but experimental work by Doctor Goldblatt of Cleveland has shown that very probably, in many cases at least, some abnormality in the blood supply to the kidney is responsible. It has been recognized for many years that high blood pressure is common in severe disease of the kidneys. Doctor Goldblatt produced permanent hypertension in dogs, comparable in all respects with hypertension in man, by narrowing the main artery to the kidney, using a silver clamp especially devised for the purpose. When the artery is narrowed in this way the kidney secretes a chemical into the blood stream which constricts the small vessels (arterioles) throughout

[2] More usual figures are 200 mm. systolic and 100 mm. diastolic.

the body. Thus, the peripheral resistance (p. 91) is increased. Such an effect, it will be understood from what has been said in regard to maintaining the normal blood pressure, must inevitably result in hypertension.

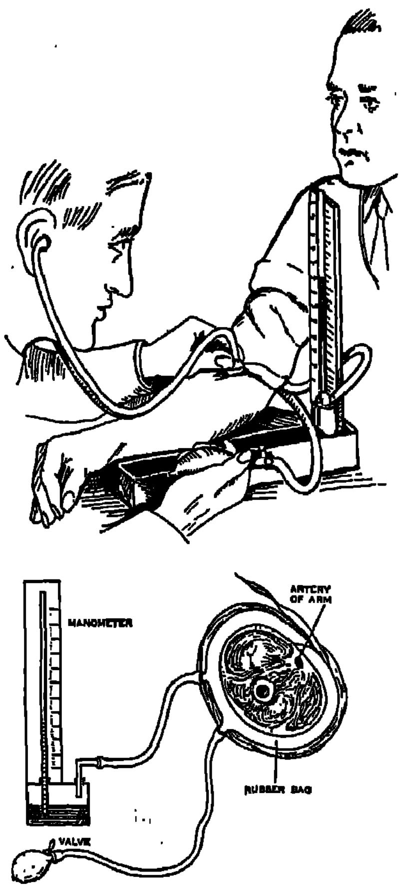


FIG. 10.4. *Top:* The manner in which the blood pressure is measured in man. This is called the auscultatory method. *Bottom:* A cross section of the arm with the armlet wrapped around it and connected with the manometer.

THE MEASUREMENT OF THE BLOOD PRESSURE IN MAN

If we wish to measure the blood pressure of a human being, we must do it indirectly, i.e., without opening an artery, as may be done in animals. The measurement is made in the following way. An airtight, flat rubber bag, covered with cotton cloth, is wrapped around the arm above the elbow (Fig. 10.4). The cuff or armlet, as it is called, is provided with two rubber tubes, which open into its interior. One of the tubes is connected with a *manometer* which consists of an upright glass tube of mercury, fixed to a millimeter scale. The other tube of the armlet is attached to a small rubber bulb provided with a valve. By means of the bulb and tube the armlet can be inflated and a pressure created in its interior. The air pressure is recorded by the manometer. It is evident that, if we can counterbalance the pressure in the large artery of the arm with air pressure and read from the manometer the value of the

air pressure used, we will know the value of the blood pressure in the artery. It is simply a matter of applying an amount of air pressure from without which will just balance the pressure within the large (brachial) artery of the arm. The pressure in the armlet is, therefore, raised by means of the bulb until no blood can pass to the section of artery below the cuff. This is indicated by the disappearance of the pulse at the wrist. The examiner then listens with a stethoscope over the artery just below the armlet as he gradually reduces the air pressure. The examiner lowers the air pressure by cautiously releasing the valve on the tubing near the bulb. The instant that the artery opens a little and allows blood to escape below the cuff, a faint tapping sound is heard. The height of the mercury column of the manometer is read at this moment; the reading represents the *systolic* pressure. The examiner continues to lower the air pressure slowly until a soft murmur is heard; all sound then disappears. The manometer reading at the instant that the change in the sound occurs represents the *diastolic pressure.*

The blood pressure varies in different parts of the circulation. It is highest in the great arteries, such as the aorta and its branches, and lowest in the great veins opening into the right ventricle. That is to say, there is a gradual fall in pressure throughout the systemic circulation from the left to the right ventricle. The pressure in the aorta is over 120 mm. Hg, whereas it is less than 1 mm. Hg in the venae cavae (p. 90).

The Difference Between Arterial and Venous Bleeding

When an accident has occurred and blood is lost, it is often important to know whether the hemorrhage is due to the opening of an artery or of a vein, since the means used to check the bleeding may be somewhat different in the two instances. The following are the distinguishing features between arterial and venous hemorrhage:

When an artery is opened:

1. The blood is bright red.
2. The blood escapes under high pressure—usually in spurts or pulses.
3. Compression of the tissues between the bleeding point and

the heart stops the bleeding. Pressure beyond this will not stop it.

When a vein is opened:

1. The blood is darker in color, for it contains a large proportion of reduced hemoglobin.

2. The blood flows more slowly; it does not escape in jets but appears to "well up."

3. The hemorrhage is checked upon the application of pressure beyond the bleeding point. Moderate pressure applied between the wound and the heart increases rather than diminishes the bleeding, since the blood is flowing toward the heart.

When the bleeding is from *capillaries*, the blood is bright and oozes slowly from the wound. The blood soon clots.

In severe hemorrhage of any kind, either external or internal, the patient should be kept perfectly quiet and free from excitement or anxiety of any sort, so that the blood pressure may be kept low. For this reason no stimulant of any sort should be given. It is a common error to give alcohol in some form or other at this time. This will only increase the force of the heart, tend to elevate the blood pressure, and increase the bleeding.

chapter 11

THE ORIGIN OF THE HEART BEAT

If we watch the heart of a living frog, we may observe waves of contraction originating near the great veins where they enter the heart and passing over the auricles and the ventricles in regular order. In the heart of man and of higher animals this wave of contraction is so rapid that its progress cannot be observed by ordinary means. The actual contraction of the muscle fibers of the heart is preceded, by a small fraction of a second, by an electrical change. The electrical changes can be recorded by means of an instrument known as an *electrocardiograph* (p. 102) and the action of the heart thus studied with precision. The underlying cause of the contraction or beat of the heart has been a question which has absorbed the interest of philosophers and scientists from the earliest times. The ancients thought that the heart's movements were presided over by a vital spirit, which entered the ventricle and, like steam or vapor, inflated the heart and then, condensing again, caused the heart to collapse. That the heart was a muscle, which contracted when it apparently collapsed, and relaxed when it appeared to become inflated, never seems to have occurred to them. It was William Harvey who showed his generation that the heart, by virtue of its muscular walls, contracted and relaxed with an alternating rhythm and discharged the blood like any pump.

The search for the cause of the heart's action.—The difficult problem still remained to be solved. What caused the heart to beat—what force started the rhythmical contractions? What was the nature of the hidden power which drove the pump? When it was discovered later that the heart was supplied with nerves, it was thought that these were responsible for the heart's contractions in much the same way as nerves cause any other muscle of the body

to contract. It was soon discovered, however, that the heart continued to beat after its nerves were divided. Ordinary muscle, of course, becomes paralyzed when its nerves are cut. So the heart's contractions could not be explained in this simple way. Also, the heart of the embryo chick commences to beat several days before any nerves or nervous tissue have grown into it. Again, it was

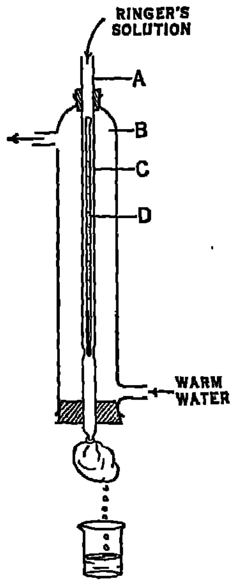


FIG. 11.1. The method of perfusing the isolated mammalian heart. Ringer's solution flows down the narrow tube under a pressure of about 120 mm. of mercury. The lower end of this tube is tied into the aorta so that the fluid will flow into the coronary arteries. Surrounding the narrow tube is a glass water jacket through which warm water circulates.

thought that the blood itself, flowing through the heart, furnished the stimulus and in some mysterious way impelled it to beat. But again it was soon found that the heart would beat for a long time after it had been removed from the body, even though it contained no blood. If a rabbit is killed, and its heart immediately removed and a warm solution (Ringer's) containing calcium, sodium, and potassium chlorides and charged with oxygen is run through it, regular beating may continue for several hours. (Figs. 11.1 and 11.2.) The isolated human heart, in the same way, has been made to beat for many hours after death. Far from being the very vulnerable organ which it is thought to be, the heart in reality can be made to perform its work for a longer time after the death of the body than most other organs. The heart of a chicken has been known to beat after the other tissues of the body are dead and quite cold,

even though no measures have been taken to keep the heart alive. The frog's heart removed from the body also continues to beat for some time. The power to contract rhythmically must lie within

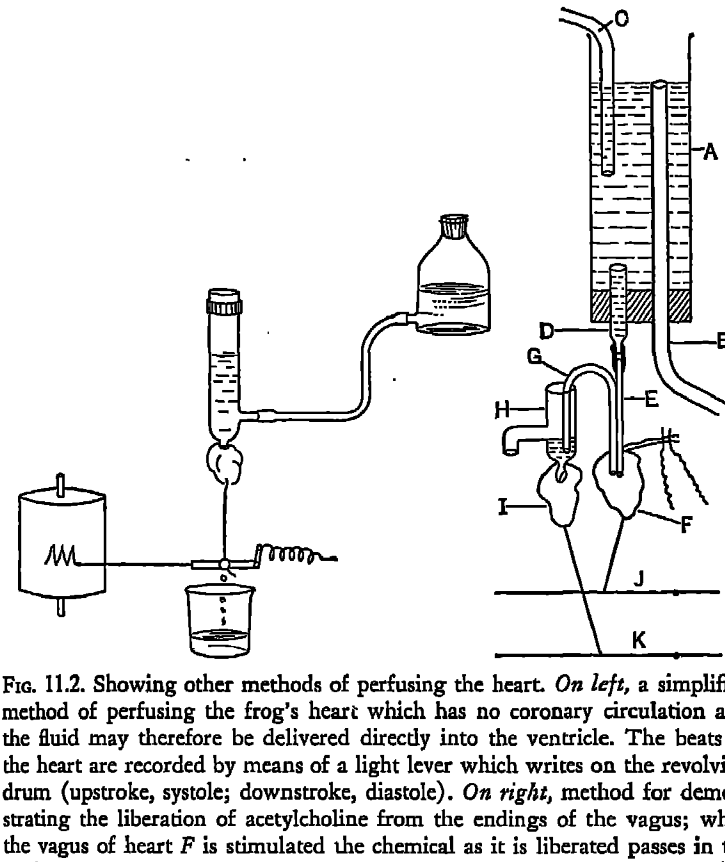


FIG. 11.2. Showing other methods of perfusing the heart. *On left,* a simplified method of perfusing the frog's heart which has no coronary circulation and the fluid may therefore be delivered directly into the ventricle. The beats of the heart are recorded by means of a light lever which writes on the revolving drum (upstroke, systole; downstroke, diastole). *On right,* method for demonstrating the liberation of acetylcholine from the endings of the vagus; when the vagus of heart *F* is stimulated the chemical as it is liberated passes in the perfusion fluid by tube *G* to vessel *H* and thence to heart *I* which slows (see p. 107). *A,* reservoir; *B,* overflow tube; *C,* inlet tube; *E,* delivery tube to heart *F; J* and *K,* recording levers.

the heart muscle itself, for even strips of muscle cut from the ventricle will continue to contract for several minutes.

Why the heart beats is a problem which scientists have not yet solved. It is a mystery which is as darkly hidden as life itself. When the egg is developing into the chicken, the tiny scrap of growing tissue which is not a heart but which will become the

heart can already be seen to be beating with a regular, even flicker.

We do know, however, that the beat in the full-grown heart starts in a little island of special tissue in the upper part of the auricle (*sino-auricular node*) and then passes as a wave over the rest of the heart. We know, also, that, each time the heart beats, a current of electricity passes through it. The origin of the beat in

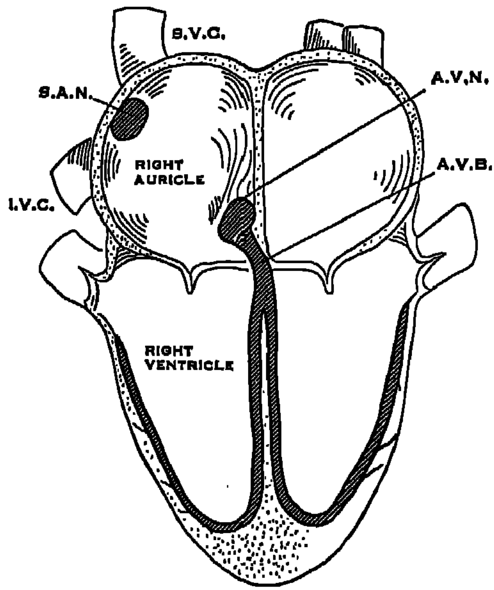


FIG. 11.3. Diagram of the conducting system of the heart. *I.V.C.*, inferior veno cava. *S.A.N.*, sino-auricular node. *S.V.C.*, superior veno cava. *A.V.N.*, auriculo-ventricular node. *A.V.B.*, auriculo-ventricular bundle.

the sino-auricular node and the passage of the contraction wave to other parts of the heart will now be described.

The sino-auricular node.—The sino-auricular node is a small island of specialized tissue. Its construction differs from that of the surrounding heart muscle, being composed of a primitive type of muscle cell and numerous nerve fibers. It lies in the upper part of the right auricle near the superior vena cava (Fig. 11.3). Here the heart beat originates. This little knot of tissue might be called the "heart of the heart," for in it occur rhythmical chemical changes which supply the "spark" or *impulse* for each systole. The rest of the heart follows its bidding. The sino-auricular node sets the pace, and on this account is called the *pacemaker* of the heart. If it sends out a rapid stream of impulses, the heart beats quickly. If the

rate at which it generates the impulses is slower, the heart, too, beats more slowly. If the sino-auricular node is removed, the heart for a time ceases to beat.

The nature of the impulse.—Though the exact nature of the impulse arising within the node is unknown, some very interesting and important features have been discovered about it. We know very little of the changes within the node which give rise to the impulse; nevertheless, once it has arisen, we may learn many things about its effects. We may know no more concerning the origin of a spark of fire or a flame, but we may watch it spread and see the results of its action. So it is with the impulse of the heart—though much of its inner nature is hidden from us, we know something of how it behaves and what it does.

Generated within the cells of the special tissue of the node, the impulse travels swiftly (1 to 5 meters per second) throughout the heart, stimulating the muscle in its course. The impulse is always accompanied by an electrical current. In animals the current may be demonstrated and its strength measured by connecting two parts of the heart, while it is beating, to a *galvanometer*—an instrument for measuring electrical currents. The actual contraction of the heart muscle follows immediately upon the passage of the current over it. It cannot be said that the impulse and the electrical change are one and the same thing. Yet the two go hand in hand, and so invariably does the electrical change accompany the impulse that the former is taken as a certain sign of the latter.

The passage of the impulse from the sino-auricular node to the different regions of the heart.—The swift message sent out from the node radiates in all directions through the muscular tissue of the auricle, making each muscle fiber which it traverses contract. Toward the lower part of the inner wall of the right auricle and above the valves opening into the right ventricle, a second node of special tissue is situated (Fig. 11.3). This is called the *auriculo-ventricular* node. It gives rise to a bundle of tissue known as the *auriculo-ventricular bundle,* which, descending to the upper border of the partition (*septum*) between the two ventricles, divides into a right and a left branch. Each of these branches divides into numerous fine twigs, which interlace with one another to form an intricate network, known as the *Purkinje system,* which is spread over the interior of the ventricles. The auriculo-ventricular node,

like a receiving station, picks up the impulses radiating through the auricular muscle from the sino-auricular node. The bundle relays the impulses again along its branches, and the numerous fine endings of these, to the individual muscle fibers of the ventricle. If the bundle should be severed or diseased so that no impulse can pass along it, the ventricle is completely cut off from the control of the pacemaker of the heart—that is, from the sino-auricular node. Division of the bundle completely interrupts communications between the auricles and the ventricles. Disease of the bundle, which gradually renders it incapable of transmitting impulses, is not uncommon. The condition is spoken of as *heart block*. The ventricles in such circumstances, however, do not, as might be expected, cease to beat. Since the block occurs gradually, they are given warning before being thrown entirely upon their own resources. They generate impulses of their own and beat independently but at a rate slower than that of the auricles.

The electrocardiograph.—The electrocardiograph[1] is an instrument used to record the electrical current generated in the human heart. Solutions of various salts (electrolytes), such as sodium, potassium and calcium chlorides, enter largely into the composition of the blood and tissue fluids. Such solutions are excellent conductors of electric currents (p. 8). The electrical changes generated in the heart muscle during its contraction are, therefore, readily conducted to remote parts of the body, even to the finger tips. In order to record the heart currents it is only necessary to connect two parts of the body with the instrument. The parts of the body employed for this purpose are the right arm and left arm, the right arm and left leg, on the left arm and left leg. These paired members are connected in turn, and in each instance a photographic record is made of the electrical effects of the cardiac contraction. Each pair of connections is referred to as a *lead* and denoted by the Roman numerals I, II, and III in the order given above. A fourth connection—between the chest overlying the heart and the left leg —is usually recorded as well. The actual connections are made by means of wires running from the electrocardiograph to small metal

[1] The electrocardiograph is a type of galvanometer. Its moving part (the shadow of which is photographed and constitutes the record) is a fine filament of spun glass which has been silvered to make it electrically conductive.

plates which are strapped to the skin, which has been previously moistened with saline or some other conductive substance (Fig. 11.4).

Figure 11.5 shows an enlarged drawing of an electrocardiographic record, or *electrocardiogram,* as it is usually called. This record

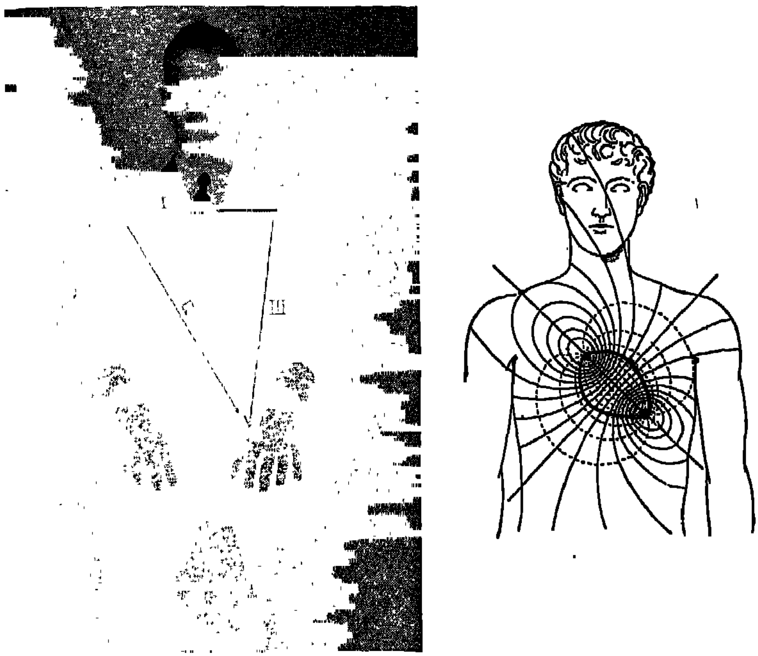
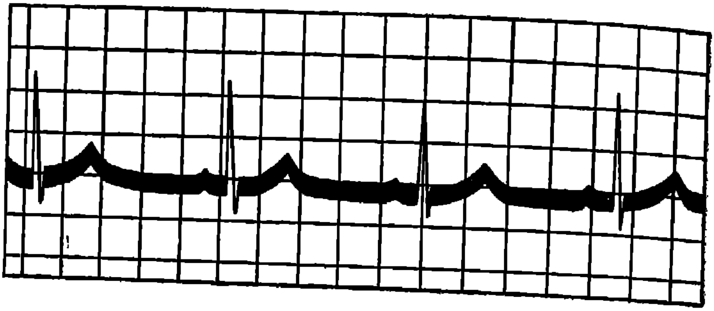


FIG. 11.4. *Left:* The electrocardiographic leads, represented by the arrows. (*After Lewis.*) *Right:* Diagram showing the electrical currents caused by the beating heart. (*After Waller.*)

has been taken from lead I, but electrocardiograms taken in other leads look very much the same to an untrained observer. At each beat of the heart the currents pass through one limb (arm or leg) of the subject, through the electrocardiograph, and back to the body through the subject's other limb; thus, the circuit is completed. Ever since the instrument was invented the waves of its record have been designated simply by the letters P, Q, R, S, and T. The wave P is caused by contraction of the auricles, and the waves Q, R, and



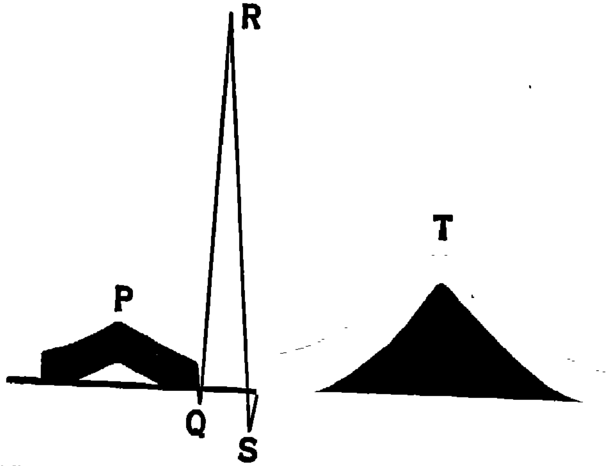


FIG. 11.5. The electrocardiogram. *Top:* A normal record taken in lead I. The horizonal lines represent tenths of millivolts, the upright lines fifths of seconds. *Bottom:* A series of curves (a complete cardiac cycle) enlarged. The different waves are known simply by the letters P, Q, R, S, and T. The wave P is caused by the contraction of the auricles; Q, R, and S by the contraction of the ventricles; and T by the relaxation of the ventricles.

S by the contraction of the ventricles.[2] The T wave is produced during the relaxation of the ventricles. When the heart is diseased the waves may be abnormal in shape or position. Thus, the physician is often able to gain valuable information concerning the condition of the heart.

[2] The electrical changes precede the actual contraction by a small fraction of a second, so that it is not strictly accurate to say that the waves are caused by the contraction.

chapter 12

THE REGULATION OF THE CIRCULATION

THE CONTROL OF THE HEART

It has been shown in the foregoing chapter what a self-reliant organ the heart is—how it has the power to perform its work though removed from the body, and to what a large extent it holds within its boundaries the organization for its government. Nevertheless, it is a small state within the larger kingdom of the body, and as such is under the control of the brain. We all know that the heart may beat faster as the result of mental excitement or emotions of various kinds. Messages of which we are unaware constantly pass from brain to heart (through *efferent nerves*) and from heart to brain (through *afferent nerves*) to direct and control cardiac action.

The nerves which carry these messages are of two types: (1) those which slow the heart, the *vagus nerves,* and (2) those which make the heart beat more quickly, the *accelerator nerves.* Both of these types of nerves, like those controlling the blood vessels (p. 108) belong to what is known as the *autonomic* or *involuntary nervous* system (p. 313). The vagus nerves belong to the *parasympathetic* division and the accelerators to the *sympathetic* division of this system.

The vagus nerves.—These nerves, two in number, arise in the *hindbrain,* or *medulla oblongata* (p. 308), and descend on either side of the neck. The vagus, as its name implies, is a wandering or vagrant nerve, in the sense that it travels far afield, and its branches go to many parts of the body. It passes through the thorax into the abdomen and in its course gives branches to the lungs,

heart, stomach, intestines, etc. At present we are concerned only with its branches to the heart (Plate IV*a*).

The function of the vagus nerves is to slow the heart and reduce the force of its beats. They serve as "brakes" to prevent the heart from racing at an unnecessarily rapid speed. Unlike the brakes on an automobile, which are brought into play only occasionally, the vagus nerves are always in action to a greater or less extent. In this action they are like brakes that are adjusted too tightly and are always dragging just a little. Or they may be compared to the reins by which a driver keeps a constant curb upon a spirited horse, for they are always exerting a restraining influence upon the action of the heart. In physiology, a continuous action of this nature is called *tone*.

When the vagus nerve of an animal is stimulated strongly, especially by an electric current, the heart is stopped. But it may start to beat again though the stimulus is continued. This phenomenon is called "the escape of the heart" from vagal control.

The accelerator nerves.—The fibers of the accelerator nerves also arise in the medulla oblongata. But they reach the heart by passing down the spinal cord and emerging in the upper part of the thoracic region. From the upper thoracic region of the cord they pass to the heart. They have an action opposite to that of the vagus. They increase the rate and force of the heart beat. As the vagus nerves act to rein in the heart, so the accelerators serve to whip it up. The accelerators are also in continuous action. That is, they too possess tone. Only a very bad driver indeed would rein in a horse at the same time that he was applying the whip, or who would drive a motor car with the brakes gripping. Yet that is the way the brain, through the vagus and accelerator nerves, governs the rate of the heart. The vagus is always slowing the heart; the accelerators are always speeding it up. This arrangement, however, possesses certain advantages. The constant effects of the two nerves upon the heart are delicately balanced one against the other. When, for example, the action of the vagus is reduced and the effect of the accelerator is increased, a more pronounced—and prompter—acceleration of the heart is brought about than would otherwise be possible.

Chemical effects of vagus and accelerator nerves.—The effects of the two sets of nerves governing the action of the heart are brought

about by the action of chemical substances produced by the nerve impulses at the nerve endings. This surprising discovery is a relatively recent one. The substance produced when the vagus becomes active is called *acetylcholine.* This chemical resembles in its action the drug known as *muscarine,* found in poisonous mushrooms. Both these substances act to slow or stop the action of the heart. The action of acetylcholine is not confined to the heart; it affects many other structures, such as blood vessels, stomach, intestines, iris, etc., and it is liberated from the endings of the nerves supplying these parts (Fig. 11.2).

It has just been stated that the action of the vagus is continuous, which means that acetylcholine is continuously being produced in small amounts. "Why then," it may be asked, "does it not enter the general circulation and produce its effects upon other organs?" Again, one may ask, "How can the heart suddenly increase its rate of beating if this chemical is present and active?" The explanation is that the minute amount of acetylcholine produced at the vagal endings by each impulse is destroyed by an enzyme called *cholies-terase* before the next impulse arrives.

The accelerator nerves and other nerves of the sympathetic nervous system also bring about their effects through the production of a chemical. This substance, if not identical with adrenalin (p. 425), resembles it very closely. It is destroyed much more slowly than acetylcholine and, entering the general circulation, produces slight side effects upon other structures of the body. But these minor effects do not cause any physiological disturbance. The chemical substance liberated at the ends of sympathetic nerves is called *sympathin* to distinguish it from the secretion of the adrenal gland (p. 425).

THE CONTROL OF THE BLOOD VESSELS

Those very small blood vessels through which the blood streams from the arteries into the capillaries and veins are called *arterioles* (p. 73). The muscle fibers composing the walls of these fine vessels run in rings around them and are under the control of the nervous system. When the fibers shorten, they act like purse strings and narrow or even completely close the vessel. When these muscles relax and lengthen, the vessel becomes wider, and more blood flows

through it. The part of the nervous system which governs these muscles lies outside the jurisdiction of the will and for this reason is known as the involuntary or *autonomic* nervous system (p. 313). It is concerned with the direction of many acts of the body which are carried out without our knowledge and independently of our wills. The actions upon the heart have been discussed; and other acts will be considered in subsequent sections of this book. It is only the effect of the autonomic nervous system upon the vessels that concerns us at the present time (Fig. 12.1).

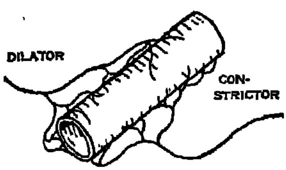


FIG. 12.1. Nerves going to the wall of an arteriole.

That the nervous system governs the caliber of the small blood vessels is a fact which everyone must have observed. We have all seen the skin flushed with blood as the result of excitement, embarrassment, or shame. We may also have seen the face become pale with fear, anger, or pain. We know, often much to our chagrin, that we can no more prevent these changes than we can alter the beating of our hearts. The blood in the countless capillary vessels gives the skin its color and warmth. When the muscular walls of the arterioles relax, such vessels dilate, the capillaries in consequence become distended with blood, and the skin becomes red and hot.

When the rings of muscle contract, the caliber of the arterioles is reduced, the capillaries receive less blood, and the skin becomes pale and cool. The capillaries are also supplied with nerves and are therefore able to adjust their capacity in accordance with the quantity of blood received through the arterioles. The muscle fibers of the arterioles may be compared to the muscle of the heart, in that the nerves by which they are supplied have opposite actions. One of these sets relaxes the muscle and so causes the vessel to dilate; they are called *vasodilator nerves*. The other set stimulates the muscular rings, causing them to contract and thus narrow or constrict the arterioles; they are called *vasoconstrictor nerves*. The vasoconstrictors belong to the sympathetic division of the autonomic nervous system; the vasodilators are derived from both the sympathetic and the parasympathetic divisions.

The nervous control of the blood vessels is of very great impor-

tance to the various functions of the body. All parts of the body do not require an equal supply of blood at the same time. One organ or tissue may be at rest while another is active. In the latter instance more fuel is burned, and more oxygen is required; therefore, resting tissues receive less and active tissues more blood. The nerves of the arterioles enable this unequal distribution of blood to be brought about. For instance, in muscular exercise the active muscles may require 10 times the quantity of blood which will satisfy them during rest. The arterioles in other regions of the body are therefore narrowed, while those which carry blood to the muscles are opened wide. A great volume of blood flows through these sluice gates into the active tissue. In the same way, after a meal the blood is turned into the digestive organs from other regions such as the muscles and brain, which in consequence are less abundantly supplied. The withdrawal of blood from the brain may account for the lazy feeling and drowsiness which follow a heavy meal. The role which the blood vessels of the skin play in regulating the body temperature will be dealt with in a later section (p. 232).

Reflex effects on heart and blood vessels.—Many afferent nerves when stimulated cause changes in the caliber of the small blood vessels (arterioles and capillaries). For example, if the large (sciatic) nerve of the lower limb be cut across and its upper end stimulated strongly, constriction of the vessels will result. A weaker stimulus applied in the same way may cause the vessels to dilate. If the effect upon the vessels is widespread and pronounced, a rise or a fall in the blood pressure may follow. These effects upon the vessels are brought about by reflexes. The impulses set up in the afferent fibers of the stimulated nerve travel to the brain, where they connect with efferent neurons (p. 270). Impulses discharged from the latter are conveyed by vasoconstrictor or vasodilator nerves to the small vessels.

Cold, heat, pain, ultraviolet light, massage, and other types of stimulus are capable of bringing about such reflex effects. They can be easily demonstrated in man. If one hand is put into cold water, for example, the vessels not only of the chilled hand but of the opposite hand as well, are constricted. Or if a breeze from a fan is allowed to blow upon the skin of the back, the mucous membranes of the nose, throat, and bronchi become pale as a result of reflex vasoconstriction.

Aortic nerve. Reflex changes in the rate of the heart can also be induced. Stimulation of one type of afferent nerve may slow the heart, whereas stimulation of another type may cause acceleration. The vagus gives off a branch high in the neck which contains afferent fibers only. It is called the *cardiac depressor,* or *aortic nerve.* Stimulation of this nerve causes reflex slowing of the heart, dilation of blood vessels throughout the body, and, as a consequence of these

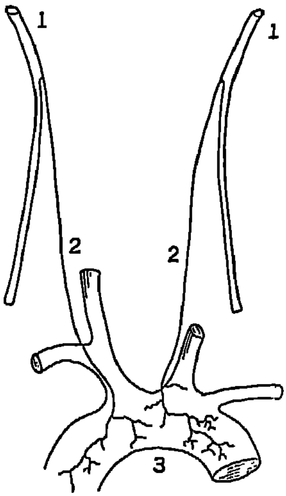


FIG. 12.2. The distribution of the aortic nerve. 1, section of vagus nerve going to the heart. 2, aortic nerve. 3, arch of the aorta.

effects, a fall in blood pressure. This nerve ends in the walls of the aorta, its fine branches extending from the arch of the vessel as far as the heart (Fig. 12.2).

The sinus nerve. The sinus nerve has a function very similar to that of the aortic nerve. It ends in the wall of the carotid sinus, which is a slight dilation of the common carotid artery at the point where it divides into the internal and external carotids. When stimulated, the sinus nerve also causes general vasodilatation, slowing of the heart, and a fall in blood pressure (Fig. 12.3).

Pressure is the physiological stimulus for the aortic and sinus nerves. Their endings in the aorta and carotid artery are extremely sensitive to changes in the pressure of blood within these vessels. In the living animal it is through this sensitivity that they fulfill their function of governing the rate of the heart and moderating

the blood pressure—i.e., preventing its rising too high or falling too low.

Because of the constant stimulus of the blood pressure upon the nerve endings, nerve impulses at low frequency—say 15 per second—are continually traveling up these nerves to the brain, from which impulses are discharged along the vasoconstrictor and vasodilator nerves to the blood vessels. Thus, in health, the blood pressure is

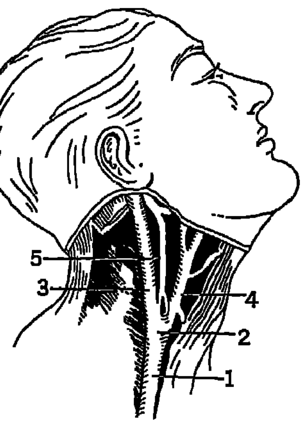


FIG. 12.3. The sinus nerve (a branch of the glossopharyngeal nerve) ending in the carotid sinus. 1, common carotid artery; 2, carotid sinus; 3, internal carotid artery; 4, external carotid artery; 5, sinus nerve.

maintained reflexly at a comparatively constant level. Should there be a tendency for the blood pressure to rise unduly the frequency of the impulses increases—i.e., the nerve endings are stimulated more strongly. Thus the heart is slowed, the vessels are dilated, and the blood pressure is prevented from rising to an extreme height. This reflex is not, however, all-powerful, for it is active in hypertension (p. 93) but cannot keep the blood pressure within normal limits.[1]

Any tendency toward a fall in blood pressure causes a reduction in the frequency of the impulses, indicating a weaker stimulation of the nerves. As a consequence, the heart rate is increased, the vessels are constricted, and the blood pressure is prevented from falling or is raised again toward normal. Owing to their governing action upon the circulation the aortic and sinus nerves are often called the *moderator nerves*.

[1] Similarly in severe hemorrhage or surgical shock it is incapable alone of restoring the blood pressure to normal. Also, in muscular exercise during which the blood pressure rises sharply these reflexes apparently are in abeyance, or other, more powerful regulating mechanisms overrule them.

chapter 13

THE CIRCULATION IN CERTAIN SPECIAL REGIONS OF THE BODY. THE EFFECT OF GRAVITY UPON THE CIRCULATION

THE CAPILLARY CIRCULATION

The capillaries are the smallest vessels of the circulatory system. They lie between the arterioles on the one side of the system and the veins on the other (Fig. 8.2). The caliber of one of these tubes may be less than the diameter of a red blood corpuscle (1/3000 inch). Ten or more of these microscopic tubes could be laid side by side upon a hair. If all the capillaries of the human body could be joined in line, they would form a strand of gossamer thinness some thousands of miles in length. The length of each capillary, however, is less than 1/10 inch. They form a maze of connecting channels in the tissues (Plate IV*b*). If the tongue or the toe web of a living frog is examined under the microscope, the red cells can be seen as they are carried through these tiny channels. For the most part, the cells pass along in single file, the vessels being too narrow to accommodate two abreast (Fig. 13.1). Some of the vessels at times may be so narrow that the corpuscle is squeezed along and pressed into a sausage shape.

Independent movements of capillaries.—Until recent years it was believed that the capillaries were unable of themselves to change their diameters. It was thought that their calibers did not alter except in a passive way—that is, simply as a result of the blood entering from the arterioles and distending them. Since their walls are made of a single layer of thin, flattened endothelial cells (p. 22), and muscle fibers are entirely absent, it seemed impossible that they

could constrict or dilate. It is known now, however, that they are capable of independent movements. They can open or close, when necessary, quite independently, of the arterioles which feed them. Their diameters, like those of the arterioles, are controlled by vasoconstrictor and vasodilator nerves.

The caliber of the arterioles and capillaries can be altered in other ways than through the nervous system. Should a capillary be stimulated mechanically—that is, by pressure or contact applied directly to the skin—it may contract so firmly that the blood within it is expelled. This effect may be shown upon the human skin. If a pencil is drawn very lightly over the skin of the back of the hand, a faint white line will appear in 3 or 4 seconds along the path taken by the pencil point. The narrow blanched area is due to the closure of the capillaries within it.

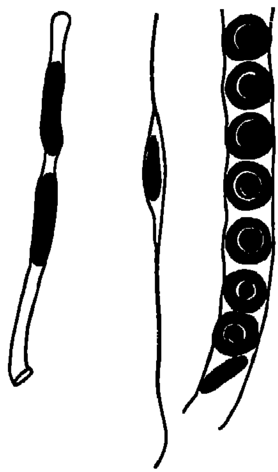


FIG. 13.1. Capillaries in different degrees of contraction.

The effects of chemicals upon the capillaries.—The capillaries are especially susceptible to the action of chemical substances. *Acids,* such as lactic and carbonic, formed in metabolic processes cause dilatation. Acetylcholine is also a dilator of capillaries. Alkalies, the hormone of the pituitary (*pituitrin*), and adrenalin (the secretion of the adrenal medulla) cause constriction. In muscular exercise lactic and carbonic acids are formed which, by dilating the small vessels in the muscles, increase greatly the flow of blood through them and thus provide for an adequate supply of oxygen. These acid products of metabolism serve a similar purpose in other active tissues—e.g., glands, brain etc.

Histamine, a chemical substance found in almost every tissue of the body, is a powerful dilator of capillaries and arterioles. A small dose injected into an animal's circulation may cause death as a result of widespread vasodilatation and a profound fall in blood pressure. Histamine is present in considerable amounts in the cells of the human skin but is "locked up" and under ordinary conditions does not escape into the general circulation. It is believed,

however, that the redness and swelling which follow stimulation of the skin, as by a pin scratch and other mechanical stimulants, the application of heat—e.g., scalding or scorching—and the sun's rays (sunburn), are caused by histamine or a histamine-like substance which the injury has caused to be liberated from the cells of the skin. The histamine then acts upon the small vessels. Sometimes in extensive mechanical stimulation of the skin the quantity escaping into the general circulation may be sufficient to cause a slight fall in blood pressure. Liberation of a similar substance is responsible in part, at least, for the heat, redness, and swelling associated with infective inflammatory conditions of the skin. Histamine is also a powerful stimulant of gastric secretion.

The Circulation Through the Heart Muscle

The heart muscle receives its blood supply through the *coronary arteries*. These are two vessels, right and left, which arise from the beginning of the aorta and, passing outward on either side, encircle the base of the heart. They are the first branches given off by the aorta. The trunk of the left coronary artery descends upon the anterior surface of the heart. The trunk of the right coronary descends upon the posterior surface (Plate IV*c*). Both vessels divide into branches which plunge into the substance of the heart. The blood, having passed through the arterioles and capillaries of the heart muscle, is collected again into veins which join together to form larger vessels. The greater proportion of the blood, after it has passed through the arterioles, capillaries, and veins of the heart muscle, is emptied into the right auricle mainly by a single large vein—the *coronary sinus*. The coronary circuit is one of the shortest in the whole body. The blood takes only two or three seconds to pass from the arterial to the venous side; for, instead of having to pass through distant parts of the body, such as the hand or foot or head, to reach the right auricle, it is short-circuited through the coronary system from the aorta to the right side of the heart. The heart, as we have seen (p. 81), performs, for its size, an enormous amount of work. In order to do this it must be richly supplied with blood. It would very soon fail should the streams of blood, which irrigate its muscle and furnish it with oxygen and nourishment, dry up. Indeed, the heart muscle ceases to contract within a second or two

after its blood supply has been arrested. When this occurs, death follows almost instantly. The abrupt arrest of the circulation to a *part* of the heart muscle is a rather common cause of sudden death in persons, especially men, over 50 years of age. It is caused by clotting of the blood within a coronary artery or one of its large branches. This condition is known as *coronary thrombosis.*

When the heart is called upon to perform a greater amount of work, as in strenuous muscular exertion, an enormously greater volume of blood flows through its substance. During bodily rest the quantity of blood which traverses the coronary vessels of the human heart is only a small fraction of the blood flow through the rest of the body. During muscular exercise the blood supplying the heart muscle may be increased several fold and may constitute a larger proportion of the total blood flow. When very heavy work is performed, two quarts of blood may flow through the coronaries each minute; this is nearly half as much as flows through the entire body during rest.

The Circulation Through the Brain

The cerebral circulation is peculiar. It differs from the circulation through other regions of the body (except the bone marrow) because the brain is enclosed in a rigid, unyielding encasement of bone —the skull. The blood enters the skull by the *carotid* and *vertebral arteries* and leaves by the jugular veins. The kidney, the muscles, the liver, or any other part of the body may hold more blood at one time than at another, because these organs can swell upon occasion and accommodate the extra supply; their vessels can dilate. Or their vessels can constrict, in which case the organ shrinks. The quantity of blood within the skull, on the other hand, can be altered very little from time to time.

This may be made clear by means of a model. Suppose that a hole is bored in the bottom of a glass flask or bottle and a length of rubber tubing fitted into the opening so made. The flask is then packed with a fine meshed sponge and filled with water. The neck of the vessel may then be closed with a cork, into which another length of rubber tubing is fixed, and arrangements may be made for water to be pumped into the sponge-filled flask by one tube

and out by the other. Such a model would imitate fairly well the cerebral circulation (Fig. 13.2). The flask and its contents represent the skull filled by the brain with its blood vessels and fluid. One

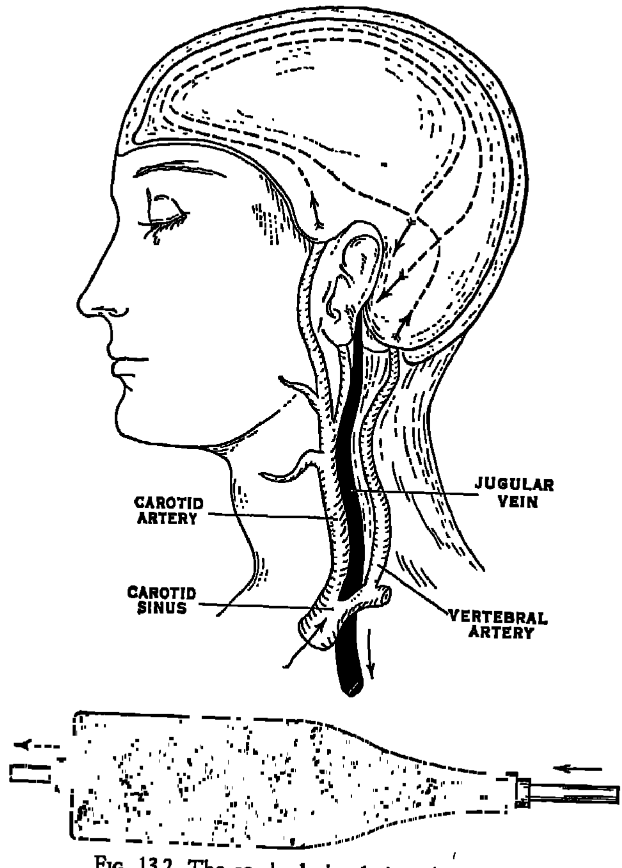


FIG. 13.2. The cerebral circulation (see text).

tube represents the carotid artery, the other the jugular vein. It is, of course, a foregone conclusion that, once the flask is filled, it will be utterly impossible to increase the quantity of fluid within it at any time. The speed at which the fluid travels through the flask and the meshes of the sponge can be increased or reduced by altering the force of the pump. But, since fluid cannot be compressed,

and the walls of the flask are unyielding, very little change in the volume of the contents can occur.[1]

Now let us suppose that the flask contained instead of the meshwork of sponge material a very intricate system of branching elastic tubes. It is obvious that we could increase the diameter of some of the tubes if we reduced the capacity of the same number of others to the same degree. So it is with the blood supply to the brain. Though the total quantity of blood within the skull can alter to only a small extent, a shift of blood from one part of the brain to another can occur. The vessels are furnished with nerves through which they are constricted or dilated. The caliber of the vessels of the brain is also influenced by the composition of the blood. In those regions of the cerebral cortex which have been observed in experimental animals an excess of carbon dioxide or a lack of oxygen causes vasodilatation.

The pressure of the cerebral circulation alters from time to time, as does also the swiftness of the blood stream. The pressure of blood within the skull changes with the blood pressure in the rest of the body. Headache is not infrequently the result of increased pressure of blood within the cranial cavity. The rupture of a small artery in the brain causes what is known as a *stroke* or *apoplexy*. This occurs more frequently in old people. The hemorrhage, by destroying some of the brain tissue which controls the movements of the muscles, causes paralysis—usually of one half of the body.

The Circulation Through the Lungs—Pulmonary Circulation

The circulation through the lungs is known as the *pulmonary*, or *lesser, circulation*. The blood leaves the right ventricle by the great *pulmonary artery*, which breaks up into small arteries and arterioles, which deliver the blood into the rich meshwork of capillaries. These delicate vessels surround the myriads (700 millions)

[1] Though the adult skull is a rigid unyielding encasement, it must be remembered that its cavity is continuous with the spinal canal and that fluid—the *cerebrospinal fluid*—fills the space that is not occupied by the brain and spinal cord. Now the joints between the vertebrae are closed by structures which are not entirely rigid. Small changes in the quantity of blood within the skull may, therefore, occur by the displacement into the spinal canal of cerebrospinal fluid, room for which is made by some bulging at the vertebral joints.

of air spaces (alveoli) of the lungs and so expose the blood to the air in these spaces, which is freshened at each breath. Each drop of blood, in its journey through the capillary gives up its load of carbon dioxide and takes on a load of oxygen, and, like a spark in the wind, the red cell instantly flashes from a dull red to a brilliant scarlet (Fig. 8.7).

If the capillaries of the lungs were joined end to end, they would form a minute tube some 3,000 miles long with a wall almost inconceivably thin. It is easy, then, to realize that, if this tube were filled with blood and surrounded with air, the respiratory gases (oxygen and carbon dioxide) would pass freely to and from the fluid within its walls. This is essentially what happens in the lungs; the capillaries, along which the red cells file singly for the most part, are entirely surrounded by air. Though each red cell is small, together they present an enormous area to the lung air. Were all these cells placed flat and edge to edge, they would cover the floor of an ordinary classroom (50 × 30 feet).

Having passed through the capillaries of the lungs, the blood is poured into the left auricle by the four pulmonary veins (p. 77). The arterioles of the lungs, like those of other regions of the body, are under the control of constrictor and dilator nerves.

The Effect of Gravity upon the Circulation

The heart chambers must be supplied regularly with blood. If sufficient blood is not carried to the right side of the heart by the great veins, the arterial blood pressure falls, for the simple reason that, like a pump of a well gone dry, the left ventricle is not properly filled and so has not enough fluid to force into the arteries. As a result, the brain is deprived of its usual supply of blood, and unconsciousness follows. A large proportion of the blood supply to the right ventricle comes from below the level of the heart—that is, from the feet, legs, thighs, and abdomen. When a person is standing upright, this mass of blood must be lifted 4 or 5 feet in order to reach the heart. If for any reason the blood is not raised to the heart, unconsciousness or *fainting,* as it is called, results. Man and the higher apes differ from four-footed animals in that their bodies are in the upright position for a great part of the time.

Their circulatory systems have developed a way to overcome the effect of gravity upon the blood in the great veins of the lower part of the body. But a rabbit, if it is held for long by the ears, will die, for its blood collects in the great veins of the abdomen and seeps into the smaller vessels, capillaries, and arterioles, and little is left to feed the heart. Sheep also often die if held in an upright position during shearing, and the heart of a snake becomes almost empty when the reptile is suspended vertically. The dog, however, can accommodate itself for some time, though imperfectly, when held upon its hind legs.

The circulation of man overcomes the effect of gravity in the following way. First, when the body rises to the upright position nerve impulses are discharged along the vasoconstrictor nerves, especially to the vessels of the abdominal organs.[2] The total capacity of these vessels is considerably reduced thereby and the blood, instead of collecting in the abdominal region under the force of gravity, flows upward to the heart.

Secondly, the muscles of the abdominal wall contract and offer a firm support to the great veins within the abdominal cavity. Thus the great veins of the abdomen, which have a large capacity, are not permitted to become distended under the weight of blood and so to deprive the heart.

Thirdly, the veins possess valves which open upward but not downward. In this way the fluid column receives further support.

Fourthly, the contraction of the muscles of the lower limbs exerts a squeezing pressure on the veins lying between them, and on account of the valves the blood is driven toward the heart.

Fifthly, the respiratory movements aid the upward flow of blood. They act in such a way as to draw the blood upward, just as water is drawn from a well by a pump. The blood, then, is literally sucked upward toward the heart every time we take a breath.

Fainting.—A person loses consciousness because the brain no longer receives its proper supply of blood. In most instances the failure of the left side of the heart to give the brain the blood which it requires is due to the fact that the right ventricle does not receive enough from the vessels below its own level. Fainting very frequently follows a sudden shock or some intense emotion. We know

[2] This is a reflex effect in which the aortic and sinus nerves play an important part.

that the caliber of the vessels in regions of the body exposed to view, such as the face, is changed by nervous impulses traveling from the brain. The face will flush with blood or blanch from emotional causes. The vessels of the abdomen may also constrict or dilate from similar causes. If they constrict, the blood pressure is likely to rise, but if great numbers of them dilate, a large proportion of the blood, instead of flowing to the heart, collects of its own weight in these vessels as in a pool. The capacity of this blood pool of the abdomen, when the vessels are dilated to their widest diameter, is so great that almost all the blood of the body can be held within it. Fatigue may cause fainting. Rising suddenly to the feet after being for a long time in a prone position may cause giddiness or fainting, for the nerves to the vessels become less acute with lack of practice and do not respond quickly when the position is changed.

The foregoing description leaves little to be said with regard to the treatment of a person in a faint. He should be kept in a horizontal position, in order that the effect of gravity upon the circulation may be abolished and the blood permitted to flow to the heart and be pumped to the brain. This, indeed, is nature's own method—a person who has fainted cures himself; for, when consciousness is lost, he no longer remains in the upright position but immediately topples over and thus annuls the effect of gravity. It is very unwise, if not actually dangerous, to support a person in the standing or sitting position during a faint, for, were his heart deprived of its due supply of blood for some time, he might die, as does the rabbit held up by its ears.

The effect of centrifugal force upon the circulation. "Blackouts."—Everyone knows that it is possible to swing a pail of water at arm's length in a horizontal circle without spilling a drop. As a result of the circular motion a force, known as *centrifugal force,* is developed which drives the water against the bottom or outermost part of the pail. In a similar manner when the body is moved at high speed in a circle with the feet directed outward and the head toward the center of the circle, the blood is driven by centrifugal force toward the lower part of the body, where the vessels become distended with blood. The brain is thus deprived of its blood supply; temporary blindness and then loss of consciousness result. These effects, which are generally referred to as *blackout,* are

likely to occur in an airman who, when flying at high velocity, makes a sharp turn with his head directed toward the center of the circular movement. A similar movement with the head directed outward drives the blood to the head; severe pain in the head and signs of concussion may be caused by this maneuver.

part IV

The Physiology of Breathing

chapter 14

THE PHYSIOLOGY OF BREATHING

Introduction.—To the men of the ancient civilizations—Greece and Rome—the rising and falling of the chest, which we call *breathing*, were full of mystery and awakened within their minds strange thoughts, rich in imaginative beauty and tinged with their inborn sense of the supernatural. The ceaseless motion in waking hours and in sleep, its commencement at birth and its departure at death, its changing rate and rhythm during excitement and fear and other emotions, led the ancients to look to their gods for an explanation. The air, which to us is but a mixture of the gases *oxygen, nitrogen,* and *carbon dioxide,* was to them something more. It contained an intangible, invisible something, a divine spirit, the psyche or soul, which they called the *pneuma,* and which, having entered the body at birth, was not to leave it again until death. This old belief has become immortalized in such words of our language as pneumatic, inspire, and expire. The last two words, consequently, came to have double meanings. To the physiologist *inspire* means to draw in the breath, *expire* to breathe out. *Inspiration* is the act of breathing in, *expiration* the act of breathing out. *Respiration* is the term used to include all the processes concerned with breathing. In everyday language the words *inspire* and *inspiration* refer to the mind or feelings, and breathing is never thought of. So also the words *expire* and *expiring*—literally, "giving up the spirit"—today are sometimes used meaning "to die" or "dying."

The term *respiration* in its broadest sense applies not only to the obvious act of animals possessing lungs or gills; it also embraces those processes carried on in nearly all living cells whereby food materials are oxidized to carbon dioxide and water. This function

of the respiratory mechanism in higher animals—that is, the use of oxygen by the tissue cells and the formation of carbon dioxide and water, with the liberation of energy from the food for the performance of work and the production of heat—is called *internal* or *tissue respiration.* The acts involved in ventilating the lungs and

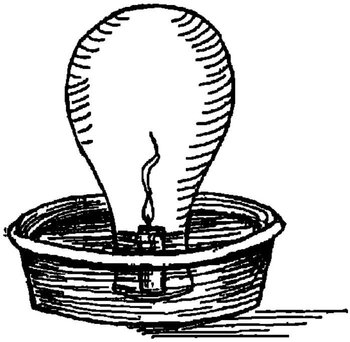


FIG. 14.1. Mayow's experiment. As the candle burned, the water rose in the small flask above the level in the surrounding water, since a part of the air (oxygen) was used up. The candle became extinguished from lack of oxygen. (*After an old drawing.*)

the exchange of gases between the atmosphere and the blood—i.e., the absorption of oxygen and the elimination of carbon dioxide—comprise *external respiration.*

It was not possible to gain any real knowledge of breathing until almost the middle of the seventeenth century, after the circulation of the blood through the lungs was demonstrated by William Harvey

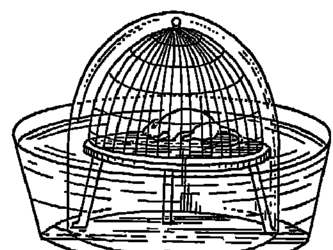
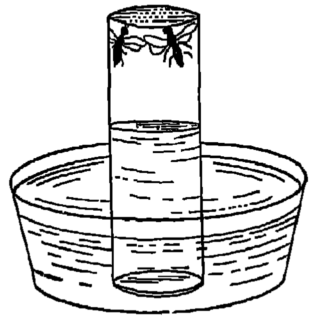


FIG. 14.2. A similar experiment to that shown in Figure 14.1, but in this case the candle was replaced by a mouse. The animal died when it had used up a large part of the oxygen contained in the air.

(1628). Further knowledge came with the invention of the microscope and the ability to study the structure of the lung, and also with the experiments of the Englishmen Mayow and Boyle (1665). These experiments and, later, those of the Swedish chemist Scheele (1770) showed that air contained an invisible, impalpable material (later

called oxygen) essential both to the life of animals and to the burning of a flame (Figs 14.1, 14.2, and 14.3). Finally, the discovery of carbon dioxide by Black and of oxygen by Priestley and Lavoisier

FIG. 14.3. An experiment similar to that shown in Figure 14.2 performed by the Swedish chemist Scheele upon the respiration of bees. The insects were placed in a glass vessel, which was inverted and its open end immersed in a larger vessel of limewater. As the bees continued to live within the flask, the volume of the air within it shrank and the water rose above the level in the surrounding vessel, for the bees had removed oxygen from the air, and the carbon dioxide which they exhaled was absorbed by the limewater.



(1785) completed the foundations upon which our modern knowledge of respiration has been built (Fig. 14.4). The pulmonary circulation has already been described (p. 117). The structure of the

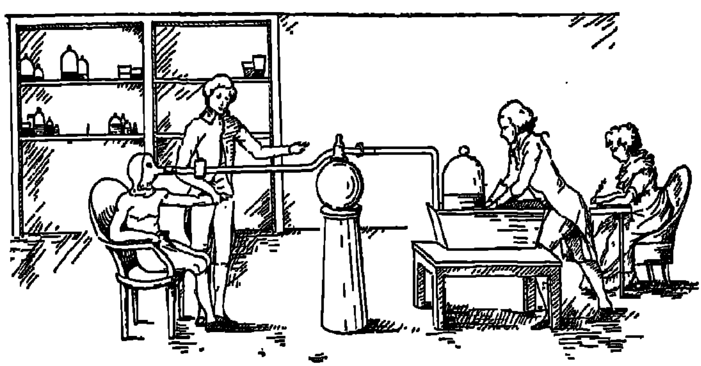


FIG. 14.4. Lavoisier, the French chemist, performing experiments upon respiration. Madame Lavoisier is seen taking notes. (*After a drawing by Madame Lavoisier.*)

air passages and lungs, and the manner in which the gases of the air (oxygen and carbon dioxide) interchange with these same gases in the blood, will now be discussed.

The Air Passages

The air, in order to reach the interior of the lungs, passes through the passages of the nose (*nasal passages*), the *pharynx*, and the windpipe (the *trachea*) and its branches (the *bronchi*). The interior

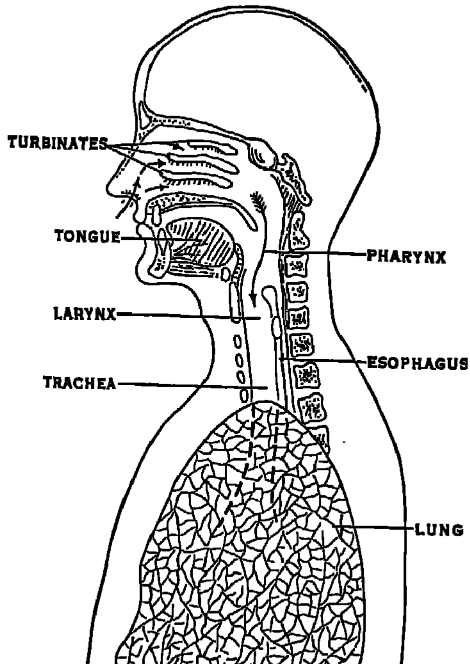


Fig. 14.5. The respiratory passages and the lungs.

of the nose is divided into right and left halves by means of a vertical partition called the *nasal septum*. Each half of the nose is further incompletely divided into four regions by three bones (*turbinates*), which, springing from the outer wall of the nose, raise the mucous membrane overlying them into irregular mounds (Fig. 14.5). The lower three horizontal grooves created in this way run from the front backward and open behind into the pharynx. They serve as airways, through which the air passes to or from the

lungs. The uppermost region, lying above the highest turbinate bone, contains the organ of smell (p. 388) and does not serve for the passage of air. The junction of the nasal passages with the pharynx is called the *naso-pharynx*. The mucous membrane of the nasal cavities is very richly supplied with blood vessels. The air, during its passage through the nose, is therefore warmed and

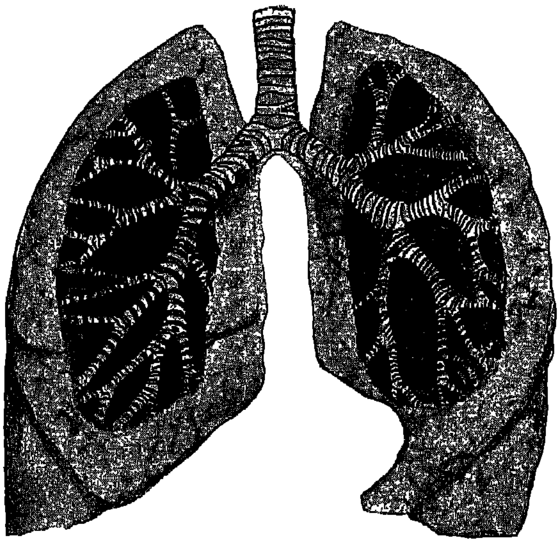


FIG. 14.6. The trachea and bronchi. Portion of the lung tissue removed to show branchings of the bronchial tree.

moistened before entering the lungs. The fine hairs about the nostrils and the cilia (p. 21) covering the nasal mucosa also serve to remove dust and other solid impurities from the air during its passage. For these reasons, if for no other, breathing through the nose is normal and healthful. The habit of mouth breathing should never be acquired. The air passes from the nose into the pharynx. The pharynx serves also for the passage of food from the mouth into the *esophagus* or food tube, but, by a special arrangement of the adjacent muscles, food is prevented from passing into the lower air passages during swallowing (p. 215).

The trachea and bronchi.—The air passes from the pharynx into the voice box, or *larynx,* which is a chamber with walls of cartilage

situated at the beginning of the *trachea,* or windpipe. The larynx can be felt in the neck as a movable, hard object and in thin persons is clearly visible. It is usually quite prominent in men and is popularly known as the "Adam's apple." The trachea commences in the lower part of the neck and passes behind the breastbone, or *sternum,* into the thorax. It is a wide flexible tube with incomplete rings of cartilage in its walls. Soon after entering the chest, it divides

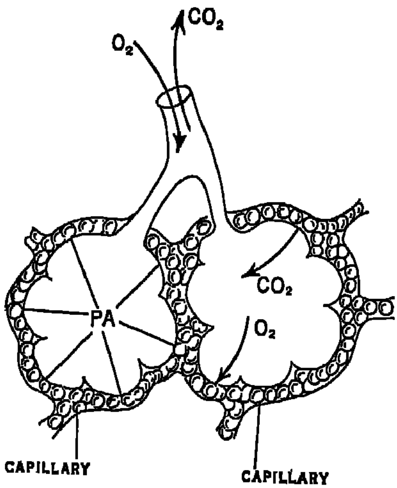


FIG. 14.7. Diagram of a bronchiole going to two lung alveoli encircled by capillaries. The small circles represent the red cells.

into two main branches, right and left, called *bronchi* (singular, *bronchus*). Each branch plunges into a lung and breaks up into numerous smaller tubes, like the roots of a tree (Fig. 14.6). The larger of these branches are also called bronchi, but the very smallest twigs are spoken of as *bronchioles.* Inflammation of the bronchi is called *bronchitis.*

The lungs.—The lungs, one might almost say, are composed of "frothed tissue," for they contain some 700 million microscopically small air spaces, like bubbles, surrounded by capillaries filled with blood. The lungs, by reason of the large amount of air which they contain, are very light and puffy; indeed, they are frequently referred to as "the lights." Unlike any other organ of the body, they float upon water. The air sacs are called *alveoli* (singular, *alveolus*). The bronchioles divide and subdivide like the rootlets of a plant. The terminal hairlike subdivisions are each surrounded by a group

of alveoli which, being in communication through the bronchial tree with the atmosphere, are always filled with air. The walls of the alveoli are extremely thin and incomplete, for they are composed of flat cells with many gaps between them.[1] Since each alveolus is surrounded by capillaries, the red cells, as they pass slowly along these vessels, are separated from the air at the most by only two membranes of the greatest possible thinness. The two lungs, one on either side, together with the heart and large blood vessels

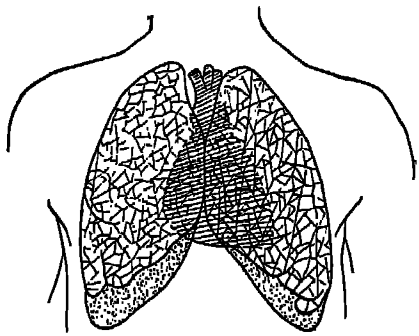


FIG. 14.8. The relation of the lungs to the heart and to the front of the chest wall.

completely fill the chest. The left lung is divided into two parts, the right into three. These divisions are called *lobes* (Figs. 14.7 and 14.8).

INSPIRATION AND EXPIRATION

The entrance of air into the lungs is called *inspiration* or *inhalation*. The exit of air is called *expiration* or *exhalation*. A double respiratory movement—inspiration and expiration—occurs from 16 to 18 times per minute. Since the air sacs are so small and so numerous, it is evident that some special means must be employed to force air into them all, during the short time occupied by an ordinary breath. In order to understand the way in which this is accomplished, the structure of the chest and the relation of the lungs to the outside air must be described.

The chest, or *thorax,* is a completely closed box. Below, a large arched sheet of muscle—the *diaphragm*—forms its floor and separates it from the abdominal cavity (Fig. 14.9). Its walls are formed

[1] Owing to the gaps in the alveolar walls the capillaries are in many places directly exposed to the lung air.

by the ribs, the spaces between which are closed by muscle—the *intercostal muscles;* in front is the breastbone. Above and behind, the thoracic box is also completely closed. Within the thorax is a thin, two-layered membrane called the pleura. One layer of this membrane lines the thorax; the other covers the surfaces of the lungs. Thus on each side of the chest a membranous sac is created called the *pleural cavity*. No space or cavity actually exists; it is

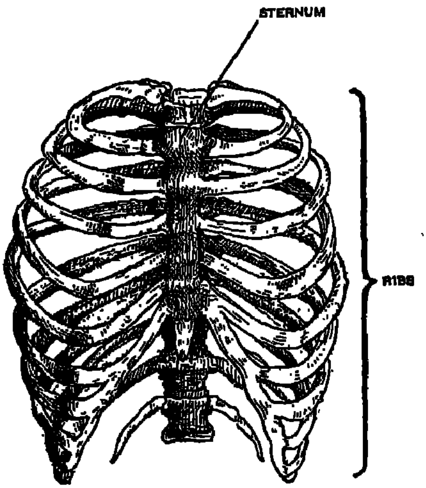


FIG. 14.9. The framework of the chest—the thoracic cage. No soft parts are shown here, but in the living body the spaces between the ribs and at the root of the neck are closed by muscles while the floor of the chest is formed by the diaphragm.

potential only, for the walls of the sac are in contact except for a thin layer of fluid which allows them to glide over one another with the respiratory movements.[2] The layers of the pleura are held together partly by this fluid but also because of a "suction"—i.e., a pressure less than that of the atmosphere—which exists between them. Should the chest wall be punctured and the pleural sac opened, air enters through the opening, the suction pressure is abolished and an actual space between the two layers is produced. The manner in which the two layers of the pleura are held together under normal circumstances may be compared to the way in which two wet glass slides adhere to one another. When they are pressed together so as to express the air from between their surfaces, the pressure of the atmosphere upon their outer surfaces holds the slides firmly

[2] When this membrane becomes inflamed, the condition is spoken of as *pleurisy;* then the rubbing of the layers together during breathing causes severe pain.

together. They can be made to glide over one another, but only by permitting a little air to pass between them can one be lifted from the other.

Thus we see that while a pressure less than that of the atmosphere exists upon the pleural surfaces of the lungs, the interior of the lungs—i.e., the air sacs—are in communication through the air passages with the atmosphere. During inspiration the thoracic cavity is increased in all its diameters; it resumes its previous size during expiration.

Whenever any cavity is increased in size, something—air, gas, or water—always tries to fill it. That is, the pressure within the enlarging cavity falls (p. 135) and the higher pressure surrounding it causes the air, gas, or water to enter it, until in the end the pressures within and without are equal. The cavity as it enlarges is said to suck air or fluid in, but actually it is the higher outside pressure which fills it to its new capacity.

The only way in which the extra space created within the thorax during inspiration can be filled is by air rushing through the trachea into the lungs and expanding them. That is actually what happens when one draws in a breath. Air at the higher pressure of the atmosphere is forced in. To put the problem in another way, let it be supposed that the upper part of the thorax is open to the outside air simply through the trachea, the lungs being absent. Were the thorax completely closed everywhere else, then, when its capacity increased, air would rush in from the outside through the trachea. When the size of the thorax became reduced again, the air would be forced out. The thoracic box would be a kind of bellows, the trachea representing the nozzle, the thoracic walls the bellows' sides. If the trachea ended below in an empty bag within the thorax, the general principle would not be altered. When the thorax increased in size, air would rush in as before, but would then fill the attached bag. The lungs essentially are no more than millions of tiny sacs, opening through the smaller tubes into the windpipe; therefore the entrance of air when the chest expands (inspiration) and the expulsion of air when the chest collapses again (expiration) can be similarly explained.

The lungs contain a large amount of tissue which is highly elastic. During inspiration, when the lungs are inflated, this tissue is

stretched; and the lungs, offering a certain resistance to this stretching force, strive, as it were, to return to their uninflated state. This causes a pull between the two layers of the pleura; but the pull is not sufficiently strong to tear them apart. When a communication is made with the atmosphere by puncturing the chest wall, and suction thus abolished, the elastic lungs recoil to their unexpanded or collapsed state. The layer of the pleura covering the lung is then drawn away from the layer lining the thorax. The actual space now

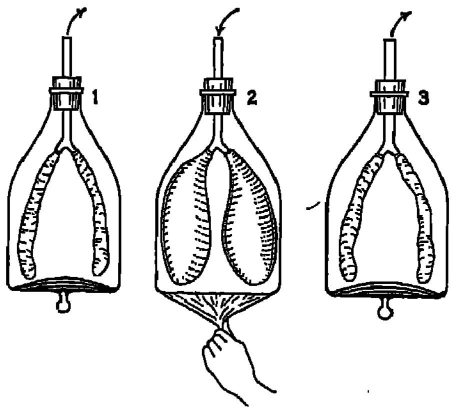


FIG. 14.10. Model to illustrate the manner in which air is taken into and expelled from the lungs. 1 and 3 represent expiration, 2 inspiration. The arrows indicate the directions of the air currents. (See text.)

created between the thoracic wall and the lung is filled with air. This condition is called *pneumothorax*. It may result from disease or from an accident. The collapsed lung cannot, so long as the opening exists or air is present in the thorax, become inflated. Sometimes, therefore, in pulmonary tuberculosis a pneumothorax is produced intentionally, usually by injecting air into the pleural cavity, the object being to bring about a cure of the diseased lung by putting it at rest.

The model in Figure 14.10 will serve to illustrate some of the principles given in the foregoing paragraphs. The glass jar is completely sealed from the air. Through the cork passes a branched tube, representing the trachea and bronchi. To each branch is attached an empty elastic bag, representing a lung. The floor is a flexible diaphragm, which can be drawn down to increase the flask's capacity. When the size of the space is increased in this way, the air pressure in the flask must tend to fall, but atmospheric air

at once flows in (or, one might say, is sucked in) through the tube to equalize the pressure. The bags are expanded by the inrush of air and continue to distend until the greater space caused by the descent of the chamber's floor is filled.

How the changes in the capacity of the thorax are brought about.—We must now study the means by which the changes in thoracic capacity are produced. The thorax is a chamber with jointed walls composed largely of bones and cartilage held together by mus-

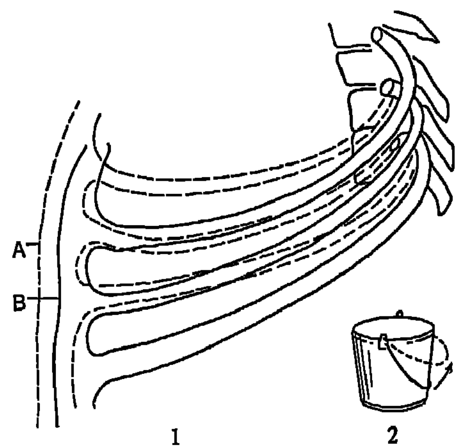


FIG. 14.11. 1. Section of the thorax viewed from the side. *A*, inspiration; *B*, expiration. This movement increases the antero-posterior diameter of the thorax. 2. The bucket-handle movement. (See text.)

cles and ligaments; it has a movable floor of muscle called the diaphragm. Like bars of a cage, the ribs, twelve on each side, form the greater part of the chest's framework (Fig. 14.9). In front the ribs (except the lower two on each side) are attached to the breastbone by cartilage. Behind they are connected to the thoracic vertebrae by movable joints. From these connections they run in a curved and slanting direction forward and for the most part slightly downward.

During inspiration the dimensions of the thoracic cavity are increased mainly by three movements.

1. By the contraction of the intercostal muscles, which lie between and are attached to each pair of ribs on either side of the chest. When these muscles contract, the front ends of the ribs are raised into a more horizontal position; thus the front-to-back diameter of the thorax is increased (Fig. 14.11-1).

2. The transverse diameter of the chest is increased by a rotation of the ribs upward and outward. This movement has been compared to that of a bucket handle as it is raised from the side of the bucket (Fig. 14.11-2).

3. The diaphragm moves downward with a piston-like action (Fig. 14.12); thus the vertical dimension of the thorax is increased. The diaphragm in its descent presses the abdominal contents downwards and causes an outward movement of the abdominal wall. About 60 percent of the air drawn into the lungs during inspiration is accounted for by the downward movement of the diaphragm. During expiration all these movements are reversed; the ribs resume their more oblique direction, and the diaphragm rises to its previous position. Air is forced out of the lungs. The movement of inspiration involves a definite though usually unconscious effort on the part of the individual—a contraction of muscles. In expiration, on the contrary, the thorax returns to its former size with little or no effort, simply as a result of muscular relaxation. The bony cage falls largely of its own weight to resume its previous size. The elasticity of the ligaments and cartilages, of the lungs themselves, and of the abdominal muscles also aids the return movement, which is therefore rather in the nature of a recoil.

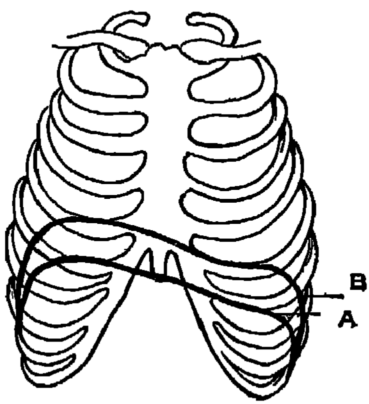


FIG. 14.12. The positions of the diaphragm during *A*, inspiration, and *B*, expiration.

The diaphragm is a muscular sheet which completely separates the thoracic from the abdominal cavity. Openings in it permit the passage of the inferior vena cava, the aorta, and the gullet (esophagus). It is arched toward the chest cavity, the liver and the stomach being fitted into its concavity. Its upper, domed surface is in contact at its center with the heart and on either side with the base of a lung. The muscular fibers of the diaphragm are attached to the vertebrae, the lower ribs, and the sternum. The fibers converge toward the central part of the diaphragm to end in a leaf-

like membranous structure called the *central tendon*. The diaphragm is the most important muscle of respiration; it is controlled by the two *phrenic nerves*, which emerge from either side of the spinal cord in the lower part of the neck. These nerves carry messages from the medulla oblongata (p. 308) to the muscle fibers. This part of the subject will be taken up more fully in Chapter 16.

chapter 15

THE PHYSIOLOGY OF BREATHING (Continued)

Atmospheric Pressure. Composition of Air. Exchange of Gases.

The atmospheric pressure.—The pressure of the air at the level of the sea, as at New York, Halifax, or San Francisco, is around 760 mm. Hg. That is, the pressure of the atmosphere will support a vertical column of mercury (which is more than 13 times heavier than water) 760 millimeters high. The pressure of the atmosphere becomes progressively lower at increasing distances above the level of the sea. The reason for this difference is that at sea level the molecules of the gases (nitrogen, oxygen, and carbon dioxide) composing the air are more closely packed and their combined weights therefore greater than at higher altitudes.

The pressure of the atmosphere is measured by means of an instrument called a *barometer*. It consists essentially of a graduated vertical glass tube, closed at its upper end, exhausted of air and filled, except for a short length above, with mercury (Fig. 15.1). The barometer was invented as an outcome of a simple experiment of the Italian physicist Torricelli (1643) which proved that the atmosphere exerted a constant pressure upon the earth. He took a glass tube, closed one end and filled it with mercury. The air, in this way, was driven out. The tube was then blocked at its open end with a finger and inverted. The blocked end was placed beneath the surface of some mercury in a small basin (Fig. 15.2). When the finger was withdrawn the mercury column fell until its upper surface was about 760 millimeters above the level of the mercury in the basin. Torricelli concluded that its further fall was prevented by the

pressure (or weight) of the atmosphere upon the surface of the mercury in the basin, for, since the space in the closed end of the tube was free of air, there was no counterbalancing pressure upon the upper surface of the mercury column.

FIG. 15.1. A barometer.

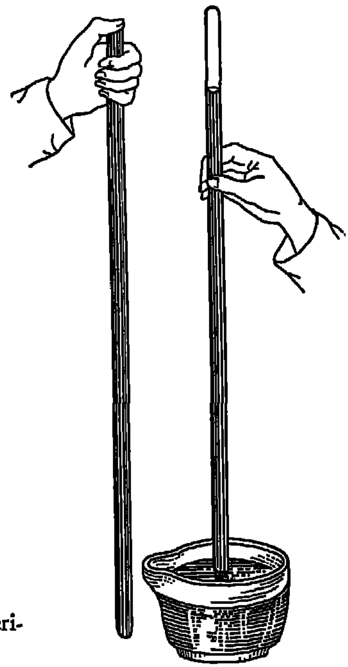


FIG. 15.2. Torricelli's experiment. (*After Kimball.*)

Some space has been given to a description of atmospheric pressure because many persons find it difficult to understand. Its effects are taken so for granted that their nature is not fully realized. For example, we speak of "drawing" water from a well or of the pump "sucking up" the water. But the pump merely creates a partial vacuum in the pipe; it is the pressure of the atmosphere upon the surface of the water in the well which forces the water up the pipe.[1] Similarly, because our bodies have become adapted to with-

[1] Therefore, as is well known, a pump, however perfectly constructed, cannot "draw" water to a greater height than about 34 feet (or 10,336 mm.), which is the equivalent of 760 mm. Hg.

stand it, we are unaware that the atmosphere exerts a tremendous pressure upon our bodies (about 1 ton to the square foot). Indeed, were the air as weightless as it seems to be, many physiological processes would have to be quite different. Were there no atmospheric pressure, air could not enter the lungs. Moreover, since there would be no counterbalancing pressure upon the body, the blood (at a pressure of 120 mm. Hg) would burst the vessels; the intestinal gases would expand and enormously distend the abdomen.

The composition of the air.—The percentages of the three gases in ordinary, fresh, dry air are as follows:

Nitrogen	79.02 [2]
Oxygen	20.94
Carbon dioxide	0.04

This is the composition of the air which we inhale (inspired air). The air we breathe out (expired air) has a lower percentage of oxygen and a higher percentage of carbon dioxide, since the air, during its stay in the lungs, has had some of the oxygen removed from it and some carbon dioxide added to it.

The table below shows the composition of expired air and of the air in the pulmonary alveoli (alveolar air). Both these airs are saturated with water vapor.

COMPOSITION OF EXPIRED AND ALVEOLAR AIRS, IN PERCENT

Gas	Expired air	Alveolar air
Nitrogen	79.7	80.3
Oxygen	16.3	14.2
Carbon dioxide	4.0	5.5

A gas or a mixture of gases, such as air, moves from a point of higher to one of lower pressure, until the pressure throughout the entire body of the gas is equal. When two or more samples of a gas at different pressures are brought together, the equalization of

[2] This percentage includes 0.94 percent argon and other rare gases; they are of no physiological importance.

pressure throughout the whole body of the gas is brought about by the diffusion and intermingling of the molecules until they are evenly distributed (Fig. 15.3). It is the incessant bombardment by the gas molecules of the walls of the containing vessel that is responsible for the pressure of the gas. Therefore, if the number of molecules within a given space is doubled—i.e., if the gas is compressed to half its previous volume—the bombardment upon the

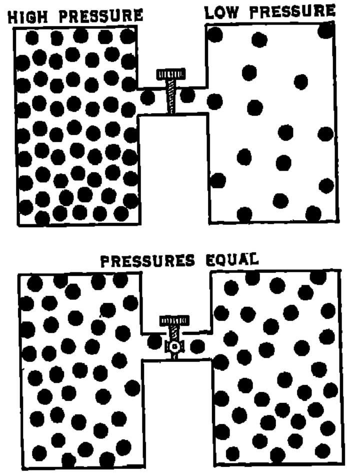


FIG. 15.3. The diffusion of a gas from a point of higher to one of lower pressure. Two vessels are represented connected by tubing provided with a tap. In the upper pair the tap is closed, and a high gas pressure is created in the left-hand vessel and a low pressure in the right-hand one. The circles represent gas molecules. In the lower vessels, the tap has been turned so that there is free communication between them. The gas molecules pass from the region of high pressure to the region of low pressure until the number of the molecules in each chamber, and so the gas pressures in the two vessels, become equal.

walls of the vessel will increase proportionately and, provided that the temperature remains the same, the gas pressure will be doubled. Reducing the concentration of the molecules within the space to half—i.e., doubling the volume of the gas—halves its pressure. These facts are embodied in *Boyle's law.*

Altering the temperature of a gas also affects the movements of its molecules (p. 6) and, consequently, its pressure. *Charles's law*[8] states that if the volume of a gas is kept constant its pressure increases by a certain ratio of the rise in temperature.

Each of the three gases—oxygen, nitrogen, and carbon dioxide—composing the atmosphere (or the individual gases in any mixture of gases) *exerts its own pressure in proportion to its percentage in the mixture and quite regardless of the presence of the other two gases.* This is *Dalton's law of partial pressures.* For example, the

[8] This is also known as the *law of Gay-Lussac.*

pressure of oxygen in the atmosphere, since it constitutes approximately 21 percent of the air, is, about 21 percent of the total pressure—that is, $^{21}/_{100} \times 760 = 160$ mm. Hg at sea level. At a higher altitude—say where the atmospheric pressure is only 600 mm. Hg—the pressure of oxygen would be only about 126 mm. Hg. At sea level nitrogen exerts a pressure nearly four times greater than that of oxygen (approximately 79 percent of 760) and carbon dioxide (0.04 percent of 760) only about 0.30 mm. Hg.

The partial pressures of nitrogen, oxygen, carbon dioxide, and water vapor in inspired (atmospheric), expired, and alveolar airs are given in the following table.

PARTIAL PRESSURES OF INSPIRED, EXPIRED, AND ALVEOLAR AIR, IN MM. HG

(Barometer 760 mm. Hg)

Gas	Inspired air	Expired air	Alveolar air
Nitrogen	596.4	568.3	571.8
Oxygen	158.3	116.2	101.2
Carbon dioxide	0.3	28.5	40.0
Water vapor	5.0	47.0	47.0
Total	760.0	760.0	760.0

The exchange of gases between the atmosphere and the body.—Nearly all living cells, from the highest to the lowest organisms, require oxygen, for, in order to obtain the necessary energy for their various activities, they must burn the carbon of food materials. The burning of carbon, whether within the cells of the body or in a fire outside the body, consists in the combination of carbon (C) with oxygen (O_2), that is, the oxidation of carbon. Carbon dioxide (CO_2), therefore, is formed, which is exhaled in the breath, or ascends in the smoke of the fire.

The respiratory and circulatory systems of animals have entered into a partnership for supplying the tissues of the body with oxygen and for removing the carbon dioxide of which the cells must be rid. The blood removes oxygen from the air in the lungs, and to the

air the blood in turn gives carbon dioxide. It will be necessary, in order that the reader may understand the manner in which these gas exchanges occur, to give an account of the principles underlying the absorption of gases by liquids.

As we already know, the pressure of a gas is high or low according to whether its molecules are in high or low concentration—i.e., whether there are many or few within a given volume. Clearly, then, if a liquid and a gas are in contact, the greater the number of gas molecules that are bombarding the liquid's surface, the greater will be the number that enter it and become dissolved. It is true, then, that *the greater the pressure of any gas in contact with a liquid, the greater will be the amount of gas which the liquid will dissolve.* This is *Henry's law of the solution of gases.*

It also follows that what has been said elsewhere with regard to a gas flowing from a point of higher to one of lower pressure must apply also to the passage of gases between liquids and the atmosphere. For example, water in an open vessel dissolves or, as we sometimes say, absorbs oxygen and other gases from the atmosphere. The amount of oxygen which it will dissolve depends, as just stated, upon the pressure of oxygen in the atmosphere. For this reason water at sea level will dissolve more oxygen than at a higher altitude. The pressure of oxygen at sea level is about 160 mm. Hg; on a high mountain top it is much lower. At any pressure the gas molecules pass into or out of a liquid until they are evenly distributed between the gas and the liquid. In other words, the pressure of oxygen or other gas to which a liquid is exposed becomes exactly the same inside the liquid as outside of it. By means of a compressing force—that is, a force which will pack the gas molecules more closely together—water and other liquids can be made to dissolve much greater quantities of oxygen and carbon dioxide than they will dissolve at the ordinary pressure of the atmosphere.

In this way such beverages as ginger ale and soda water are charged with carbon dioxide; they are exposed to a high pressure of the gas. An airtight cap is afterwards applied to the bottle to prevent the closely crowded molecules of gas within the liquid from escaping. Upon the removal of the cap, the imprisoned gas rushes out as bubbles until the pressure in the liquid and in the atmosphere are the same; bubbling then ceases. The ginger ale charged in this way is said to have a high pressure of CO_2, but its pressure

of O_2 will be no higher than the pressure of the latter gas in ordinary air, for oxygen was not forced into it under pressure. Yet oxygen also could be forced into a liquid by exposing the liquid to a high oxygen pressure. When the fluid was exposed again to the outside air, the oxygen would escape until its pressure equaled the oxygen pressure in the atmosphere.

The exchange of gases between aveolar air and blood and between tissues and blood is carried out according to the principles just described. The air, when it fills the air sacs of the lungs, comes into contact with the blood surrounding these spaces (Figs. 8.7 and 14.7). The venous blood coming to the lungs has a high pressure of CO_2, which it has absorbed from the tissues, but, since it has at the same time as it received CO_2 given up some of its O_2, the pressure of the latter gas in the venous blood is low. The alveolar air, on the other hand, has a lower pressure of CO_2 but a higher pressure of O_2, since the air sacs are being continually ventilated by the inspired air. As a result of these differences of pressure, CO_2 passes into the alveolar air, and O_2 passes from the alveolar air into the blood. The blood becomes bright and arterial in character because it has a higher pressure of O_2 and a lower pressure of CO_2 than when it entered the lungs. The arterial blood is carried to the tissues, where the process is reversed. The O_2 pressure of the tissues is low, since O_2 is being continuously used, and the CO_2 pressure is high, since this gas is being continuously formed. Thus O_2 passes from arterial blood to the tissues, and CO_2 passes from the tissues into the blood. This exchange of gases in the tissues produces the alteration in the blood which gives it its venous character.

The partial pressures in arterial and venous blood are given in the following table.

PARTIAL PRESSURES IN ARTERIAL AND VENOUS BLOOD, IN MM. HG

(Barometer 760 mm. Hg)

Gas	Arterial blood	Venous blood
Nitrogen	570	570
Oxygen	100	40
Carbon dioxide	40	46
Water vapor	47	47

The Carriage of the Gases in the Blood

The carriage of oxygen and its delivery to the tissues.—Were the blood a simple fluid—no more than plasma (p. 40)—the exchange of gases between it and the alveolar air and tissues would be fully described by the account given in the preceding paragraphs. The quantity of O_2, however, which could be forced into a cell-free fluid such as plasma by the pressure of this gas in the lungs would be very small indeed—about .38 part to every 100 parts of plasma—a little less than pure water can carry. The quantity of oxygen carried in this way would not suffice for the maintenance of life for a second. The body, even at rest, requires each minute 50 times more oxygen than could be supplied by the *fluid portion* of the blood. But, as we know, the blood contains red cells, and they hold hemoglobin, which can absorb enormous amounts of oxygen—19 or 20 parts for each 100 parts of blood. The red cells, therefore, serve for the storage and transportation of oxygen. Oxygen, then, is held in blood in two ways—a small quantity is dissolved in the plasma and a much greater part is combined chemically with the hemoglobin.

The quantity of O_2 with which the hemoglobin can combine depends, nevertheless, upon the pressure of the gas, that is, the quantity dissolved in the plasma, which, in turn is dependent upon the pressure of oxygen in the alveolar air (Fig. 15.4). When the pressure of oxygen is high, as in arterial plasma, the red cells hold nearly all (95 percent) the oxygen with which the hemoglobin can possibly combine—i.e., the hemoglobin is 95 percent saturated with oxygen. Reaching the capillaries, the hemoglobin gives up about one third of its oxygen store owing to the low pressure of oxygen in the tissue fluids. The pressure of oxygen in the cells of the tissues is always low, for here it is being used up. These cells draw their supply from the fluids which bathe them; the tissue fluids replenish their oxygen supply from the plasma, and the plasma receives its oxygen from the hemoglobin. So, as the blood flows through the capillaries, the pressure of oxygen in the plasma falls; consequently, the hemoglobin unloads a part of its oxygen again to the plasma, which in turn delivers it to the tissue

fluids. These finally deliver it to the cells, where the oxygen pressure is lower still.

The carriage of carbon dioxide.—The passage of carbon dioxide into and from the blood is, as in the case of oxygen, simply a

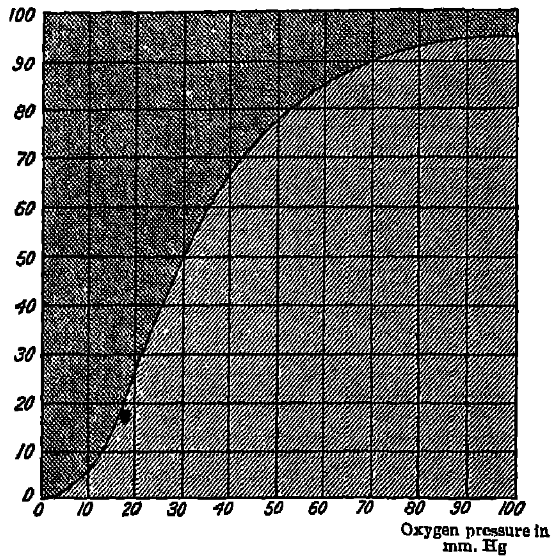


FIG. 15.4. Curve to show the degree of saturation of hemoglobin with oxygen at different pressures of oxygen. This is called the *oxygen dissociation curve of hemoglobin.* Note that as the oxygen pressure increases (read from left to right along the horizontal lines) the hemoglobin becomes more saturated (read from below upward along the vertical lines). At an O_2 pressure of 100 mm. of mercury the hemoglobin is more than 95 percent saturated. The pressure of oxygen in the lungs is about 100 mm. of mercury. Also note that the curve is somewhat S-shaped. To find the oxygen-saturation of hemoglobin at a given oxygen pressure, say for example at 60 mm. of mercury, run a pencil upward from the number 60 till it meets the curve. A glance to the left along the horizontal line cutting the curve at this point will show that the saturation is about 83 percent. (*After Barcroft.*)

matter of differences between the partial pressures of carbon dioxide in air, blood, and tissues. But the fall in pressure is reversed, namely, from the tissues to the lungs. Only a very small quantity of carbon dioxide is in ordinary or *simple solution* in the plasma; by far the greater part is stored and carried in *chemical combination.* Of the latter, 10 percent or less is loosely united to hemoglo-

bin in the form of a compound called *carbhemoglobin*. The remainder of the carbon dioxide entering the capillaries from the tissues is combined with sodium as *sodium bicarbonate*.[4]

The quantity of carbon dioxide present as sodium bicarbonate increases when the partial pressure of the gas in the plasma rises, and diminishes when the pressure in the plasma falls. So, the venous blood coming from the tissues, since its CO_2 pressure is higher—i.e., it contains more of the gas in solution—also holds a greater quantity in the combined form than does the arterial blood. The blood in the capillaries of the lungs "bubbles" off some of its CO_2 in simple solution. As a result of this the CO_2 pressure of the plasma falls; part of the gas carried as bicarbonate is then released from combination and diffuses into the alveolar air. The arterial plasma must then have a lower pressure of carbon dioxide and a smaller quantity of sodium bicarbonate.

The carriage of the respiratory gases reminds one of a well-organized transportation system. The blood, having delivered its freight of gas, always takes on a return load. Carbon dioxide is delivered into alveolar air, while an oxygen load is taken on. Oxygen is later unloaded in the tissues, and a return load of carbon dioxide is received. The unloading of oxygen in the tissues is facilitated by the loading of carbon dioxide, and the loading of oxygen in the lungs encourages the unloading of carbon dioxide.

The Effects of Excessively High or Low Atmospheric Pressures

Low atmospheric pressures. Mountain sickness.—The pressure of the atmosphere at mountain heights may be less than half that at sea level. An expedition to scale Mount Everest in the Himalayas was undertaken in 1924, and a height of some 28,000 feet above sea level was reached. At this height the pressure of the atmosphere is only about 250 mm. Hg. The *proportion* of oxygen in mountain air is, however, the same as that at sea level—namely,

[4] Carbon dioxide, when it enters the plasma from the tissue fluids, penetrates the red blood cells, where it is acted upon by an enzyme known as *carbonic anhydrase* and converted to carbonic acid ($CO_2 + H_2O \xrightarrow{\text{carbonic anhydrase}} H_2CO_3$). In the capillaries of the lungs this enzyme brings about the reverse change—namely, the breakdown of carbonic acid to carbon dioxide and water ($H_2CO_3 \xrightarrow{\text{carbonic anhydrase}} CO_2 + H_2O$). The gas is eliminated in the expired air.

about 21 percent. So the oxygen pressure at 28,000 feet is no more than ($^{21}/_{100} \times 250$) = 52.5 mm. Hg (see p. 143). It is clear that at this pressure the blood could take up only a fraction of the amount of oxygen which it could take up at the pressure existing at sea level (about 160 mm.). The lack of oxygen, or *anoxia,* has very serious effects. Vomiting, headache, distress in breathing, and blueness of the face and hands result, and finally unconsciousness and death. This condition, known as *mountain sickness,* increases in severity as higher and higher altitudes are reached. At levels of 10,000 feet or so the symptoms are mild, but in the Mount Everest expedition, in which nearly three times this height was reached, certain members of the party suffered severely. The rate at which the ascent is made also influences the severity of the effects. If a person makes the ascent slowly, he may reach a height of 28,000 feet or perhaps more without the aid of oxygen, because the body becomes acclimated to the rarefied air.

It is evident then, that in order to enable a person to climb to a very high altitude or to ascend to a great height in an airplane, some means—such as a storage tank of pure oxygen, tubing, and a suitably constructed face mask—must be provided for supplying oxygen; and thus preventing anoxia. Flights without oxygen to heights greater than 12,000 or 13,000 feet are decidedly risky. At altitudes of 30,000 feet or more a storage tank and mask are quite inadequate to prevent oxygen lack. Some form of airtight cabinet which can be filled with air under a pressure equivalent to that at a height of about 8,000 feet must then be used. Should the aviator, as a result of some accident, be exposed to the rarefied air at 35,000 feet or more, the acute anoxia would cause unconsciousness within a few seconds.

High atmospheric pressures. Caisson disease.—Equally serious effects may result from exposure to high barometric pressures. In laying the foundations for bridge or quay piers, large wooden chambers called *caissons* are constructed and lowered beneath the water to the river's bed. In order to expel and keep out the water from the interior of the caisson so that men may work inside, air is pumped into it under high pressure. The workmen draw this compressed air into their lungs, and the gases, nitrogen, oxygen, and carbon dioxide, are forced into their blood under high pressures and in a manner comparable to that whereby beverages are charged

with carbon dioxide. So long as the workman remains in the caisson no ill effects, as a rule, are produced; but should he suddenly be brought to the surface and exposed to the ordinary atmospheric pressure, the gases (mostly nitrogen) which have been dissolved at high pressure in his plasma and tissue fluids escape and form bubbles for the same reason that bubbles of carbon dioxide gas appear in ginger ale when the bottle cap is removed. The bubbles of nitrogen in the capillaries of the nervous system cause paralysis of various regions of the body. The gas bubbles may form in and actually tear the soft nervous tissue. If a vital area in the medulla is involved, death results. The cause of the serious effects has not always been clearly understood, and several deaths have occurred in the past. Now, however, the men, after their shift in the caisson, are raised to the surface but are not permitted to enter a lower barometric pressure immediately. On the contrary, they are kept in an airtight chamber, in which the pressure, to start with, is the same or only a little lower than that within the caisson which they have left. The pressure is then slowly reduced. The long period of *gradual decompression* avoids any violent discharge of gases from the blood or tissue fluids and so prevents the formation of bubbles and the occurrence of the serious effects mentioned above.

The severe pains in the muscles and joints which caisson workers suffer when *rapidly* decompressed are known as *the bends*. They are due apparently to the bubbles of nitrogen pressing upon sensitive structures. Rapid ascents, such as those often made by military aviators, from sea level to a very high altitude—i.e., to where the barometric pressure is considerably lower than 760 mm. Hg—may cause effects similar to those suffered by caisson workers, though much less severe.

Another effect of rapid airplane ascents is the expansion of gases in the intestine (p. 140) which, though not dangerous, may cause much discomfort and pain. In rapid descents the sharp rise in barometric pressure may cause rupture of the eardrum (p. 378).

chapter 16

THE CONTROL OF THE RESPIRATIONS. ARTIFICIAL RESPIRATION

THE CONTROL OF THE RESPIRATION

For the control of many functions of the body two means are employed. The heart and blood vessels and the intestines and stomach, for example, are controlled by nerves as well as by chemical substances carried to them in the blood stream. The respiratory movements also are governed by these two means. It is usual, therefore, to speak of the *nervous control* of respiration and the *chemical control.*

The nervous control.—It is a matter of common knowledge that by an effort of the will we can modify the respiratory movements. The breath can be held, or one can, within limits, breathe quickly or slowly, lightly or deeply. In singing or talking the respirations are modified voluntarily to suit our purpose. Yet during sleep, as well as most of the time while we are awake the respirations are continued automatically and unconsciously. In the lowest part of the brain—the medulla oblongata (p. 308)—there lies a collection of nerve cells which transmits impulses in a continuous stream. The impulses pass along nerves to the various muscles of respiration to cause the rhythmical contractions and relaxations responsible for the alternate enlargement and collapse of the thoracic cavity. The phrenic nerves, which supply the diaphragm, have already been mentioned (p. 137). The collection of nerve cells in the medulla is called the *respiratory center.* Should this center be seriously injured, as by a fracture of the skull or by a bullet wound, or become paralyzed by pressure or by poisons, such as morphine, anesthetics,

etc., it can no longer send impulses to the respiratory muscles, and death results.

The respiratory center is readily influenced by the rate at which it receives impulses from neighboring or distant parts of the body along various afferent nerves. That is, the respiratory movements are to a large extent under reflex (p. 282) control. Stimulation of the nerves of the nose, as by some pungent odor, may cause sudden suspension of the breath. This effect apparently serves to prevent further inhalation of the irritant gas. Dropping water on the bill of a duck causes a similar response; when the bird dives and its bill touches the water, the breath is held without the need of any conscious effort upon the part of the animal itself. Irritating substances, such as pepper, etc., also stimulate the nerves of the nasal mucosa and cause *sneezing*, which is simply a modified respiration.

The respirations are also altered in rate and depth as a result of impulses reaching the respiratory center along the vagus nerve endings within the lungs themselves or in the abdominal organs. Heat or cold applied to the skin, as by a hot bath or a cold plunge, stimulates the nerve endings upon the body's surface and causes a reflex change in the rate of breathing. As a matter of fact, the stimulation of almost any sensory nerve in the body, if intense enough, will cause reflex changes in respiration (Fig. 16.1).

Coughing, sneezing, and *hiccuping* are modifications of the respiratory act brought about reflexly.

Coughing is caused, as a rule, by stimulation of sensory nerves in the larynx or trachea by an irritant—a vapor, mucus, or a small foreign particle. Or it may be the result of some inflammatory condition of the lower respiratory passages causing irritation of the sensitive nerve endings. A reflex through the respiratory center follows. A cough consists first of a quick inspiration; then follows immediately a forcible expiration with the laryngeal opening closed, resulting in the production of a high pressure within the lungs. The larynx is then suddenly opened, and the compressed air escapes explosively; the air blast, rushing through the air passages, sweeps any offending material away.

Sneezing consists of a deep inspiration followed by an explosive expiration which drives a blast of air through the nose and mouth.

Hiccuping results from some irritation of the diaphragm which causes it to contract spasmodically at irregular intervals. It is usu-

ally of little concern and arises from some temporary gastric disturbance, but occasionally it is a symptom of serious disease.

Laughing, crying, sobbing, and *yawning* are types of respiration modified by nervous impulses passing from the higher (conscious) regions of the brain to the respiratory center. Emotions other than

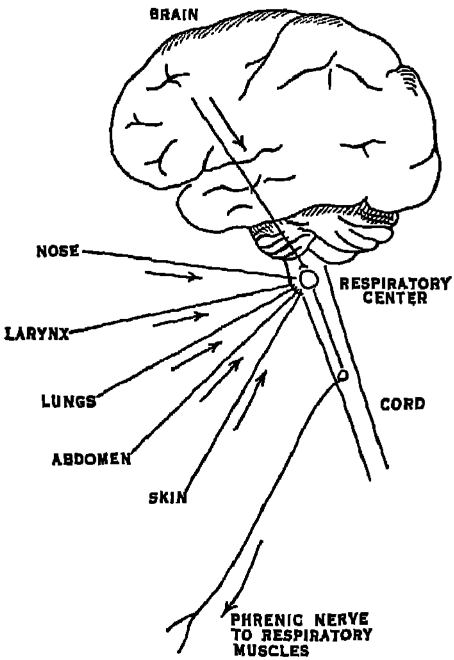


FIG. 16.1. Diagram to illustrate how the respiratory movements may be influenced by reflexes carried out through the respiratory center. The phrenic nerve supplies the diaphragm. The line passing from the cerebrum to the respiratory center represents the course of impulses from intellectual and emotional parts of the brain which have an influence upon the respiratory movements.

amusement or grief, such as anger, excitement, and fear, also influence the activity of the center.

Control by the carotid body.—Near the carotid sinus, the importance of which in the control of the circulation has been discussed (p. 110), there is to be found a small gland-like structure known as the *carotid body.* The carotid body is provided with small branches of the sinus nerve. The cells of which it is composed are stimulated by carbon dioxide when this gas is in high concentration in the arterial blood. They are also excited by a low content of oxygen in the blood. Impulses are set up in the sinus nerve by the stimulation of these peculiar cells when either of these extremes in blood composition exists. The impulses are conveyed to the re-

spiratory center and increase its activity—i.e., the respirations are increased in rate and depth. Since it requires a rather large excess of carbon dioxide or a severe oxygen lack in the blood to increase the respirations, it is doubtful whether the carotid body plays an important part in the control of respiration under ordinary physiological conditions.

The chemical control.—The carbon dioxide in the blood flowing through the respiratory center provides the stimulus upon which the continuous flow of impulses to the diaphragm and other muscles of respiration largely depends. Even a slight increase in the amount of carbon dioxide in the blood increases the rate and depth of breathing. A reduction in the carbon dioxide of the blood slows the rate and reduces the depth of breathing and, if there is a great reduction, the respirations may cease entirely for a time. For these reasons the quantity of carbon dioxide in the blood in health is kept practically the same at all times. It is on this account that one cannot hold the breath for very long. Carbon dioxide accumulates in the blood and stimulates the center so forcibly that no effort of the will can prevent an inspiration or expiration. On the other hand, should a person breathe rapidly and deeply (*forced breathing*) for some minutes and then stop breathing, he may have no desire to breathe for several minutes, since large quantities of carbon dioxide have been removed from the blood by the forced breathing, and the quantity which remains does not suffice to stimulate the respiratory center. Not until carbon dioxide re-accumulates do the respirations recommence. This state, in which the respirations are temporarily suspended, is spoken of as *apnea* (literally, no breathing). If oxygen is breathed before and during the period of forced breathing, the period of apnea may persist for fifteen minutes. Even a short period of forced breathing alone before a dive will permit one to remain under water for a much longer time than usual. The reader, however, should be warned that breathing forcibly for more than a few seconds is risky, for it produces in some persons cramps or even convulsions.

We may conclude, then, that in the action of carbon dioxide the body possesses an efficiently adjusted mechanism for the control of the rate and depth of breathing—a regulation more delicate than that possessed by the most precisely regulated machine. When it is remembered that carbon dioxide is a waste gas, which must be

removed from the body, we cannot but be overwhelmed with admiration for the ingenuity of the chemical control of breathing. Through the power of carbon dioxide to stimulate the respiratory center and through this the respiratory movements, it calls into play the means for its own removal.

Though seldom called into play, acids, such as lactic acid, if in excess in the blood, stimulate the respiratory center, both directly and through the carotid body. Oxygen lack does not stimulate the respiratory center directly; its effect upon the nerve cells is depressant.

Artificial Respiration

When the respiratory mechanism has failed, as in the apparently drowned or as a result of carbon monoxide poisoning, electrocution or other cause, some artificial means must be employed to bring air into the lungs until natural breathing is resumed or until all hope of this occurring has been abandoned.

In any method of artificial respiration promptness in starting the treatment is of first importance. So long as the heart beats, the tissues for a time are able to gain a small amount of oxygen from the circulating blood. But the heart is peculiarly susceptible to oxygen lack and, unless the air in the lungs can be renewed and the blood oxygenated, it will soon cease to beat. Nervous tissue also, especially the higher centers of the brain, does not survive for more than a few minutes after its oxygen supply has been arrested. When the heart can no longer maintain the circulation, therefore, methods of resuscitation are usually of no avail. However, it is often impossible for one who is not medically qualified to detect a weakly beating heart, and for this reason artificial respiration should be continued until natural breathing has been restored or until a physician has pronounced the death of the patient. Not until then should hope be abandoned.[1]

Most methods of artificial respiration are designed to increase and reduce alternately the capacity of the thorax in such a way as to *draw* air into the lungs and expel it again. Thus the blood is oxygenated and carbon dioxide removed. Several methods have been devised for this purpose. The one most widely known and,

[1] If a physician is not available, efforts at resuscitation should be persisted in until *rigor mortis* (stiffness of the muscles after death) is clearly evident.

all things considered, probably the most useful, is the *Schafer prone pressure method*. This will now be described.

After water, mucus, or other obstruction to the free passage of air has been removed from his mouth and throat, and all clothing about the neck, waist, and chest loosened, the patient is placed in the prone position—i.e., chest and abdomen downward—upon the ground or some form of support. His face is turned to one side (Fig. 16.2) and one arm extended in front along the ground while the other is bent at the elbow and provides a rest for the side of the head. The operator, with trunk erect, kneels astride the patient a little below the level of the hips and facing his back. The operator places the palms of his hands over the subject's lower ribs on either side so that his fingers pointing downward curve around this part of the chest. Then, with his arms held straight and rigid, he swings forward slowly until his shoulders are in a vertical line with his hands, and brings his weight to bear upon the patient's ribs (Fig. 16.2 *top*). Thus air is expelled from the chest.[2] This movement should take about 2 seconds. The operator then releases the pressure and resumes his original erect position, but in about 2 seconds swings forward again. The double movement is repeated 12 or 15 times per minute.

Care should be taken to keep the patient warm throughout the entire procedure. When consciousness returns a hot drink may be given.

Mechanical devices, such as the pulmotor, which *force* air into the lungs and draw it out again, though less exacting upon the endurance of rescue workers, are not so satisfactory, because unless the degree of ventilation of the lungs is carefully controlled the carbon dioxide of the blood may be reduced to a dangerous level and collapse of the circulation result.

When artificial respiration must be continued for long periods—days, weeks or longer—the apparatus originally devised by Dr. Thunberg, the Swedish physiologist, and improved by Philip Drinker, must be used. This apparatus, which is popularly known as the "iron lung," consists of an airtight cabinet in which the patient is placed except for his head, which protrudes from an opening hermetically sealed around his neck. By means of a

[2] Not only is the lower part of the patient's chest compressed but the diaphragm is pushed up as well.

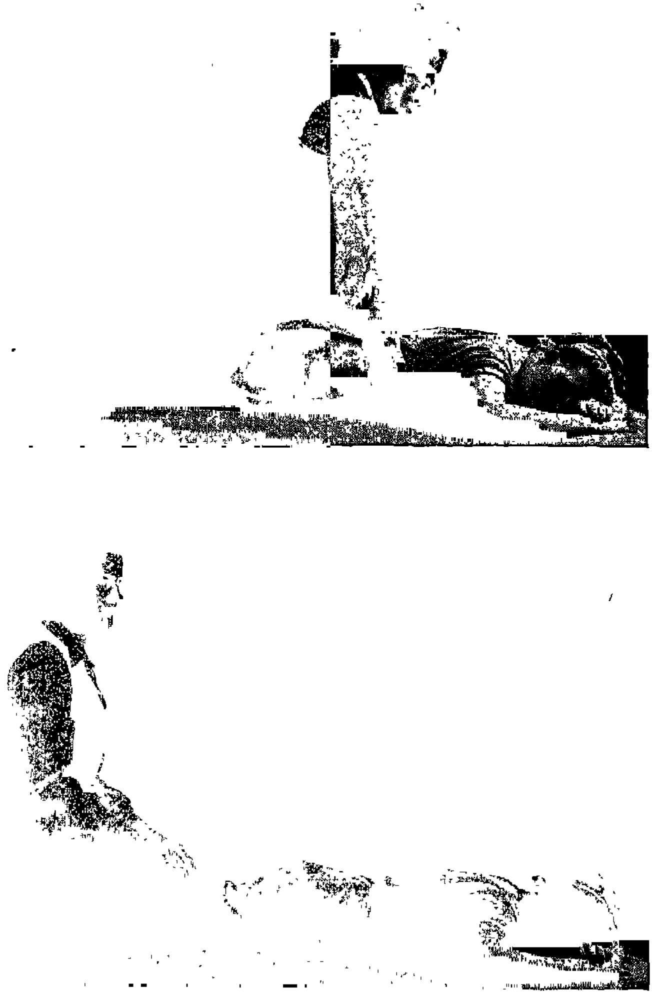


FIG. 16.2. The Schafer prone pressure method of artificial respiration. (*American Red Cross photograph.*)

motor the air pressure within the chamber is alternately lowered and raised at the rate of normal respiration. When the pressure is reduced below that of the atmosphere (p. 133) the chest expands and air enters the lungs. Air is expelled from the lungs when at the next moment the pressure is increased again. Thus, inspiration and expiration can be induced rhythmically for indefinite periods. It is only in exceptional circumstances, such as in hospital cases, that an apparatus of the kind described is available. A great many lives have been saved by prompt application of the prone pressure method of respiration.

chapter 17

THE VOICE

The mode of production of the human voice, with its varied tones, its range of pitch, and its volume, has long aroused the interest of physiologists. As an instrument of sound, the voice box or larynx, with the cavities of the mouth, throat, trachea, and lungs,

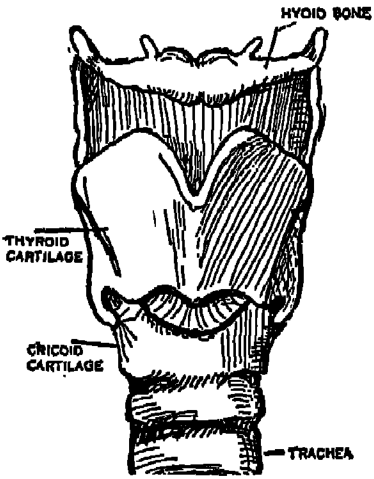


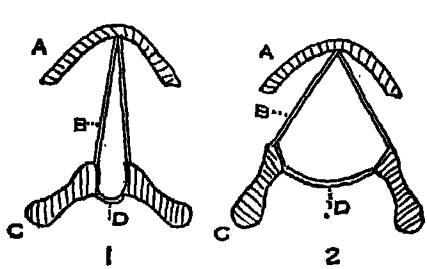
FIG. 17.1. The larynx and upper rings of the trachea. The *hyoid* is a small bone lying near the root of the tongue. The *thyroid* cartilage forms the front and side walls of the larynx. The *cricoid* is a circle of cartilage shaped like a signet ring, lying between the larynx above and the trachea below.

may be compared to the pipes of an organ. Certain notes can be played by the organist which imitate the human voice in a truly remarkable way. A reed and the column of air in the organ pipe are set into vibration by an air blast. In a somewhat similar manner the vocal cords within the larynx are thrown into vibration by air expelled from the lungs. The nose, mouth, throat, and chest serve as resonating chambers.

The larynx (Fig. 17.1) lies at the upper end of the trachea. Its walls are formed of cartilage and lined with mucous membrane;

the vocal cords are two thin-edged bands or membranes lying within. The cords run from front to rear, being attached behind to two small cartilaginous bodies (the *arytenoid cartilages*) and fixed in front to the wall of the larynx. By the contraction of small muscles attached to them, the arytenoid cartilages can be rotated when necessary. By this means the vocal cords can be swung away from one another—that is, outward against the walls of the larynx (Fig. 17.2), or inward toward one another until only a small chink remains between them. Ordinarily the cords lie against the wall of the larynx, and the gap separating them is wide, and no sound

FIG. 17.2. The vocal cords viewed from above. *A*, the front of the larynx (thyroid cartilage). *B*, the vocal cords. *C*, the arytenoid cartilages. *D*, the posterior wall of the larynx. 1, the cords brought toward the mid-line during speech; 2, the cords swung outward at ordinary times.



is produced during the passage of the breath. During speech they are brought toward one another and into the current of air expelled from the lungs, which, being unable to escape except through the narrowed opening, sets the edges of the cords into vibration. By means of slender muscles running in the cords themselves they may be tightened or slackened.

Sound possesses three properties: loudness, pitch, and quality or timbre.

The *loudness* of the voice depends upon the energy with which the vocal cords vibrate; the greater the pressure under which the air is expired, and the greater the movements made by the cords, the louder will be the sound.

The *pitch* depends upon the length and tightness of the cords, which, in turn, determines the frequency of their vibrations. In children and women the cords are short, and the voice is high-pitched. In men the cords are longer, and the voice is deeper. All of us can adjust the tension and to some extent the length of our vocal cords and so alter the pitch of the voice, but trained singers have developed this ability to the greatest degree. (See also p. 379.)

The *quality* or *timbre* of our voices depends on the number and intensity of the overtones or harmonics which are produced, and these in turn depend upon the shape and capacity of the resonating chambers—the mouth, the trachea, and the chest. Training of the voice consists very largely in modification of the mouth and throat cavities so that the sound produced in the larynx receives the greatest possible number of these harmonics or supplementary tones.

In speech the musical sounds produced by the vibration of the vocal cords are modified by the numerous changes which may be

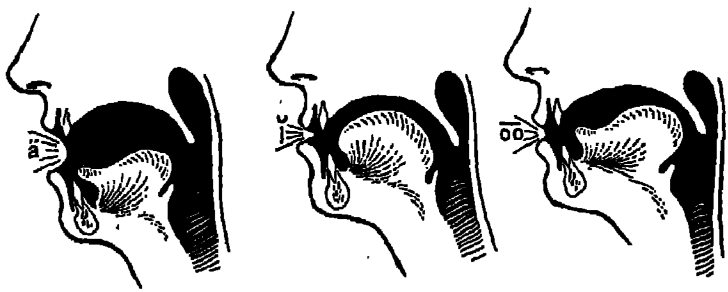


FIG. 17.3. The positions of the lips and tongue and the shape of the mouth cavity when pronouncing ä, ī and o͞o.

made in the size and shape of the air passages—the pharynx and the mouth. The vowel sounds, *a, e, i, o, u,* are formed in the lower air passages, and the mouth cavity assumes positions which are characteristic for each vowel (Fig. 17.3). When we whisper, these sounds may be produced simply by placing the mouth in the required position without vibration of the cords. The consonants are formed by interrupting to different degrees the expired air in various parts of the vocal pathway. The reader may learn a great deal about these phenomena by studying the mechanism of production of his own voice.

As many of us fully realize, children utilize their vocal organs soon after birth and continue by this means to make known their discomfort for some months or years. Very soon the character of the crying and the tones of the voice vary under different conditions—for example, in pain or in hunger. This dissimilarity may be recognized at first only by a well "tuned" ear. Laughter may be indulged in as early as the third week. Vowel sounds are learned

first and consonants somewhat later. The child's speech is at first very incoordinate, as are its muscular movements, but it gradually learns, usually by imitation, to pronounce words and to construct phrases and sentences. The function of speech in the adult is very complex, involving one of the most intricate activities of the higher centers of the brain.

chapter 18

MUSCULAR EXERCISE AND PHYSICAL TRAINING

Muscular Exercise

Introduction.—When a person contemplates strenuous muscular exercise, nervous impulses are sent out from the brain to various parts of the body. The heart beats faster, and more blood is pumped around the circulation. Breathing is more rapid, and more oxygen is taken into the lungs. The muscles become more tense. In these and in many other ways, the body is prepared for exertion even before the exercise begins. As soon as the active contraction of muscles commences, the mechanisms mentioned above are set in motion more vigorously. Many of the changes which take place are brought about by the liberation of an interesting chemical substance, *adrenaline,* from the little glands (*adrenals,* or *suprarenals*), which are situated just above the kidneys (p. 424). The suprarenal glands receive nervous impulses just before and during muscular exercise and in response discharge their internal secretion into the blood stream. The same changes are produced by administering to a human subject adrenaline prepared from beef adrenal glands.

In strenuous muscular exercise the body may use from 15 to 20 times as much oxygen as it requires when at rest. The body temperature may rise to 103 or 104 degrees Fahrenheit, as a result of the heat produced by muscular exertion. The heart in a strong healthy man is capable of pumping over 30 liters of blood each minute during the height of the exercise, and the skeletal muscles may develop energy at the rate of half a horsepower per minute. The readily available food reserves in the body are very rapidly used up during vigorous muscular work.

The fuel of muscular exercise.—The type of food used as fuel by the muscles during exercise may be ascertained by analysis of the inspired and expired airs during and after the conclusion of the work. Information can also be gained from studies of the changes in the composition of the blood and urine which have resulted from the exercise. These studies have shown that sugars are the principal but not the only fuel used. Sugar is capable of providing energy very quickly. As a result of very prolonged strenuous exercise, the amount of sugar available in the body may be lowered to a level at which various characteristic symptoms appear. Feeding sugar helps to correct this condition. In marathon races it is now common practice for the contestants to eat sugar in some form or other at regular intervals during the race. There is no depletion of sugar as a result of short periods of strenuous exercise, and no good effects can be expected from administering it. The fact that sugar is used in very large amounts during muscular exercise does not indicate that the carbohydrate in the diet of athletes should be increased. The body is able to form sufficient sugar from the adequate diet discussed under nutrition, except during very prolonged violent exertion, when the store of quickly available sugar is used up.

Recovery after exercise. Oxygen debt.—When a person indulges in moderate or strenuous exercise, the amount of oxygen taken into the body during the exercise is never sufficient to meet the requirement. Therefore, after the exercise stops, oxygen is consumed at a rate in excess of the normal resting consumption until the deficiency is made good. This oxygen intake may be determined by means of the apparatus described in Chapter 24. It may be said that during exercise the body goes into debt for oxygen, and that this debt is repaid during the recovery period which follows the exercise. The amount of the debt varies with the physical condition of the individual, with his state of training for the particular exercise, and with the intensity and extent of the exercise taken.

It is surprising that in so far as the oxygen consumption is concerned an hour may be necessary for recovery from a 100-yard sprint. After prolonged violent exertion, the recovery period may be two hours or longer.

No attempt will be made here to discuss methods of physical training. We are interested only in the physiological mechanisms by which an individual is able to increase his ability to perform

various muscular exercises. The fact that practice enables a person to perform a given exercise more efficiently, and for longer periods of time, needs no illustration. The remarkable endurance and efficiency of the trained runner or oarsman is, however, worthy of comment. The marathon runner may travel 25 miles in two and a half hours.

The changes which take place in the body as a result of graded physical exercise.—*The lungs.* The volume of air which can be forced out of the lungs after they have been fully inflated—that is, after a maximum inspiration—is termed the *vital capacity*. If the vital capacity of a sedentary individual is determined by having him expire through an air meter, and the individual then takes a series of exercises which are carefully graded so that respiratory processes are stimulated unduly, the vital capacity over a period of time will be found to have increased. That is, training increases the quantity of air which the lungs can hold.

The heart. The healthy heart of an athlete is able to increase enormously its output of blood when the demands of the contracting muscles for oxygen are increased. It has been stated elsewhere that the output of the heart is usually increased both by increasing the quantity of blood ejected at each beat and by increasing the number of beats per minute. The heart of a sedentary person depends, as a rule, more upon cardiac acceleration than does the heart of the athlete. Some famous athletes increase their heart rate surprisingly little, during even strenuous exercise, the great increase in cardiac output of which they are capable being brought about by the ejection of a much larger amount of blood at each heart beat. The heart rate returns to the resting level much more quickly in the trained than in the untrained individual after the same amount of exercise. The same is true of the respiratory rate.

As a result of physical training the healthy heart becomes only slightly larger—a purely physiological increase in bulk commensurate with the greater development of the skeletal muscles. No great enlargement ever occurs unless the heart is diseased. Furthermore, heart disease is never caused by athletics. If the heart shows great enlargement or other signs of disease during athletic training, it may be taken for granted that some cardiac abnormality existed before training was started or developed during its course from some other cause.

The blood. The number of red blood cells may be slightly increased. The increase in the amount of hemoglobin enables the blood to carry greater amount of oxygen. Apart from the effect of physical training upon the manufacture of red cells, the spleen contracts during effort and forces an extra quantity of blood rich in red cells into the circulation (p. 57).

The muscles. Although there is no change in the number of muscle fibers as a result of training, the size and strength of each fiber is greatly increased. It is an interesting fact that the maximum improvement is obtained within two or three weeks from the beginning of training in some muscle groups, and that the muscles return to their previous condition within three weeks of the cessation of the special exercise. The carbohydrate reserve in muscle increases as a result of training.

Elimination of superfluous movements. A very great improvement in the physical efficiency of an individual may be secured by the careful elimination of muscular movements which are not essential for the specific exercise involved. For example, unnecessary movement of the arms or shoulders may help to exhaust a runner. The strongest muscle groups may not be utilized to the greatest advantage, and it is often possible to correct this situation and thus to improve the performance. When superfluous movements are eliminated, the available energy may be expended much more profitably.

Nerve pathways. The factors referred to previously are not sufficient entirely to account for the increased efficiency with which certain muscular exercises are performed as a result of practice. We say that such and such a movement has become a habit, or that the person is used to it. This phenomenon is referred to by physiologists as *facilitation.* The various nerve pathways which are traveled by the several messages—brain to hand, brain to foot, etc.—become better fitted to carry these messages as a result of each experience, and the particular act or series of acts is performed with greater precision and ease.

part V

The Physiology of Digestion

chapter 19

GENERAL PRINCIPLES INVOLVED IN THE DIGESTION AND ABSORPTION OF FOOD

For descriptive purposes it is convenient to classify the processes of digestion into two groups which can be dealt with separately: (1) those concerned with the secretion of the digestive juices and the chemical changes in the food which these juices bring about, and (2) the movements of the different regions of the digestive tube and the mechanical effects of these movements upon the food.

A word must first be said concerning the characters of the food—the raw material from which the laboratories and mills of the digestive tract derive those elements upon which the body depends for energy and growth. (See also Part VI.)

The Food

It scarcely seems necessary to explain what is meant by the word *food*. Yet science likes to be very precise and is not satisfied with merely saying that food is something which we eat. The scientific description of a food is that it is a substance which furnishes the body with *energy*, gives the body material for its *growth*, or enables the body to *replace tissue* which has been worn out. Some foods do only one or other of these things; others do all three. These latter are complete and perfect foods.

Though there are a great many kinds of food—bread, cheese, butter, eggs, meat, potatoes, etc.—there are only three materials which go into the making of all foods, no matter of what type they may be. A great many different kinds of buildings can be made from the three materials, wood, stone, and iron; so a great

variety of foods are built from the three materials *carbohydrates, fats,* and *proteins.* Other substances, such as vitamins (p. 247) and various salts of lime, iron, iodine, etc., though not foods in the strictest sense, are also essential to a wholesome diet.

Carbohydrates.—There are two main classes of carbohydrate used as food, the sugars and the starches. Among the edible sugars are

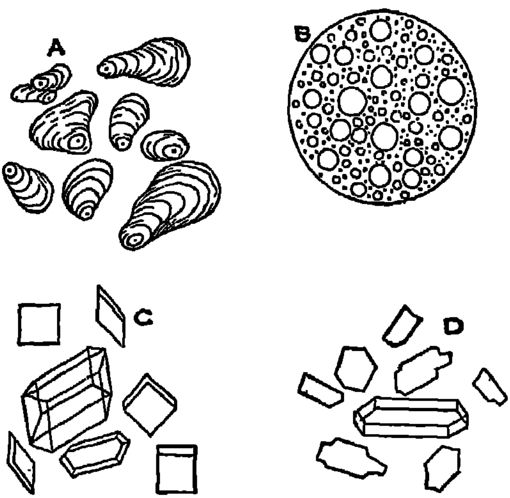


FIG. 19.1. The appearance of several food materials beneath the microscope. *A,* starch grains. *B,* milk, showing droplets of fat. *C,* crystals of cane sugar. *D,* crystals of glucose.

glucose, fructose, and *galactose, sucrose* (cane sugar), *maltose* (malt sugar), and *lactose* (milk sugar). Glucose, fructose, and galactose belong to the group of sugars known as *monosaccharides.* Their molecules are composed of 6 atoms of carbon and 6 molecules of water ($C_6H_{12}O_6$); they are, therefore, also called *hexoses* (Gk. *hex* = six). The molecules of the other three sugars—sucrose, maltose, and lactose—consist of two hexose molecules joined together. They are therefore called *disaccharides.* The molecules of the starches are composed of large groups of hexose molecules. They belong to the great class of carbohydrates known as *polysaccharides* (Gk. *poly* = many). *Potatoes; bread, cakes,* and other foods made from *flour; rice; puddings;* and *blancmange* are composed largely of starch (Fig. 19.1). All starchy or sugary materials

are merely different types of carbohydrate food. Carbohydrates come mainly from the vegetable kingdom.[1] The plant builds them up from the carbon dioxide of the air and water drawn from the ground. They are, therefore, simply carbon and water; hence their name (Gk. *carbo* = charcoal; *hydor* = water). It is perhaps hard to realize that such dry substances as sugar and flour contain large amounts of water. This is because the water is bound up so very closely with the carbon that only by the application of a great heat can it be separated. If a carbohydrate, such as sugar or flour, were put into a hot oven and left until it had become completely charred to a black mass, we would then have separated it into its two chief constituents. The black mass is almost pure carbon; the water has been driven off as steam.

Fats.—It is scarcely necessary to describe a fat. It, too, is largely carbon in combination with hydrogen and a small proportion of oxygen. There are animal fats, such as *lard, butter, suet, cream,* and fat of *egg-yolk*. There are also vegetable fats, such as *olive oil, cotton-seed oil, peanut oil,* etc.

The molecule of an ordinary fat consists of one molecule of glycerine combined with three molecules of a fatty acid, as shown in the following diagram:

```
            / fatty acid [2]
glycerine —— fatty acid
            \ fatty acid
```

The fatty acids in the common fats (or *triglycerides* as they may also be called) are *stearic, oleic,* and *palmitic*. According to the fatty acid with which the glycerine is combined the corresponding fats are called, respectively, *tristearin, triolein,* and *tripalmitin*. Animal and vegetable fats are a mixture mainly of these three fats.

[1] A small amount of a type of starch (glycogen) is also found in the muscles and livers of animals (pp. 209 and 237).

[2] The following is the molecular structure of a fat (tristearin):

$$\text{glycerine}\left\{\begin{array}{l} CH_2O—CH_{18}H_{35}O \text{ (stearic acid)} \\ \quad | \\ CH_2O—CH_{18}H_{35}O \text{ (stearic acid)} \\ \quad | \\ CH_2O—CH_{18}H_{35}O \text{ (stearic acid)} \end{array}\right.$$

Tristearin predominates in beef fat, triolein in olive oil and other vegetable fats, and human fat is chiefly triolein and tripalmitin.

The absence of certain fatty acids from the diet causes nutritional defects which are relieved by adding to the diet the missing acids in very small amounts (p. 247).

A List of Several Foods Classified According to Their Compositions

Cane sugar Maple sugar and sirup Corn sirup Corn starch Honey	Carbohydrates
Beef fat Lard Butter Olive and peanut oils	Fats
Lean meat Fish	Proteins
Eggs Cheese	Contain fat and protein
Bread White and brown flour Porridge, shredded wheat Potatoes, cabbage, rice	Contain both carbohydrates and proteins
Nuts Milk Beans	Contain carbohydrates, fats, and proteins

Proteins.—It is a more difficult task to describe clearly just what is meant by a protein. On page 14, it has been said that protoplasm —the basis of all vegetable and animal life—is composed mostly of protein, salts, and water. Muscle or meat is very largely protoplasm; so too, then, it is mostly protein. The white of egg also is almost pure protein and water. Anything living must be composed, in part at least, of protoplasm; many foods derived from the vegetable

kingdom, then, also contain protein material. A grain of wheat, for instance, from which we get our flour, contains about 12 percent of protein. The potato too, though largely starch, also contains a certain amount of protein. Other vegetable substances, such as peas and beans, are very rich in protein materials. Cow's milk, as well as containing fat, sugar, and water, is over 3 percent protein, and, since it contains all three of the food materials, it is an excellent food. Cheese is the protein and the fat of milk. Bread (chiefly carbohydrate) and cheese (protein and fat), then, should make a pretty complete diet, provided the necessary vitamins and salts are present, and indeed these foods form the diet of many peoples in different parts of the world.

Protein, like the other two food materials—carbohydrates and fats—contains a large proportion of carbon. Protein, however, contains large amounts of nitrogen—an element which is absent from the other two. We can understand how very important it is that the body should obtain a certain amount of protein in one way or another. How else could we obtain the nitrogen to build up the protein in our muscles, brain, sinews, and bone? The air is about 80 percent nitrogen, but unfortunately the body is unable to take nitrogen from the air and make any use of it. Protein also contains sulfur and usually phosphorus—elements which are necessary for building protoplasm. Carbohydrate and fat may serve as fuel for the body to burn and so provide energy, but, since these substances do not contain any nitrogen whatsoever, they cannot build up the protoplasm of which our bodies are largely composed. Protein of the food alone can built protein within the body. (See also Chap. 26.)

An automobile engine takes in gasoline and burns it to obtain the energy for driving its wheels. It uses oil to prevent wearing of the engine parts. But it would be absurd to think that either the gasoline or the oil could replace a worn part of the engine. It is just as impossible for carbohydrate and fat to replace worn parts of the body;[3] much less can they support body growth. Protein alone can do these things. How superior, then, as a machine is the body to the automobile! How wonderful we would think it, could

[3] Fatty acids in small amounts are required, however, for the construction and repair of the essential fatty envelopes and framework of cells.

we put something into the gasoline tank which would not only help to drive the engine but also replace the steel as it became old and worn. Yet that is the part played by the protein in our food.

Protein material is made up of a large number of small units bound together into larger particles. The constituent units are slightly different from one another, though in general they are all very much alike. As a class they are called *amino acids,* but each kind has been given a special name. The simplest is glycocoll[4] (or glycine). As we shall see presently, it is the function of the digestive juices secreted into the stomach and intestine to break down the large molecule of protein into the individual amino acids of which it is composed. Until this has been done, protein cannot be used by the body. The amino acids must pass individually into the blood and be carried to the cells of the body, where they are combined again into molecules of protein. A list of some of the commoner articles of diet with their compositions in carbohydrate, fat, and protein is given on page 226.

The General Plan of the Digestive System

The digestive tract, or alimentary canal as it is also called, consists of the mouth, the pharynx, the esophagus or gullet, the stomach, and the intestines. The human canal is some 30 to 32 feet long. Throughout its entire length its work is directed toward the preparation of the food for absorption into the blood. This is the final aim of the whole; yet the several regions of the digestive tract are each possessed of individual and very special features which enable them to contribute most effectively toward the common purpose—namely the digestion and solution of the food. The reader should study Figures 19.2 and 19.3 in order that he may become familiar with the different parts of the digestive system.

The movements of the different parts of the digestive tract will be described later (Chap. 23). These include the act of swallowing and the movements of the stomach and intestines. The chemical changes brought about in the food by the various digestive juices will be described now.

[4] The molecular structure of glycocoll is

$$\begin{array}{l} CH_2\text{—}NH_2. \\ | \\ COOH \end{array}$$

How Food Is Prepared for Absorption into the Blood

Little of our food, whether carbohydrate, fat, or protein, is capable in its unaltered form of nourishing the body. It must first

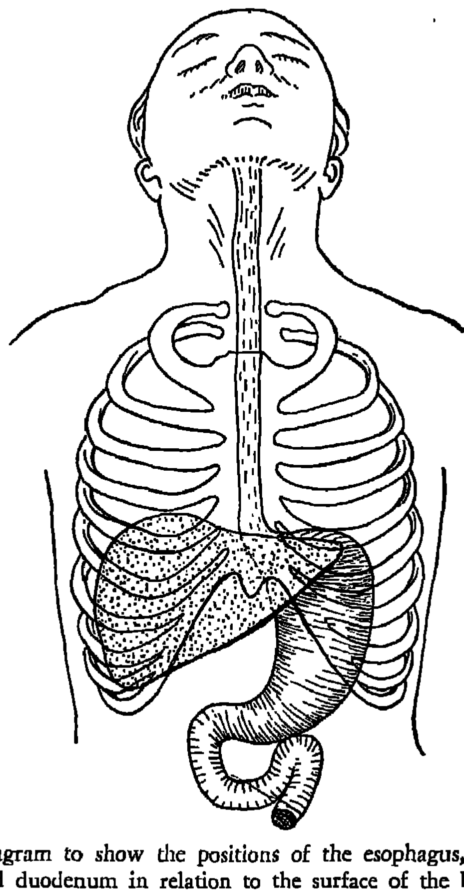


Fig. 19.2. Diagram to show the positions of the esophagus, liver, stomach, and duodenum in relation to the surface of the body.

be digested. That means that it must undergo certain chemical changes. The large molecules of proteins, carbohydrates, and fats are much too large to be absorbed into the blood through the mucous membrane of the stomach and intestine. (See *colloids,* p. 7.) Even should they pass through, they would be too large

for use by the cells of the tissues.[5] The digestive juices must act upon the large molecules of the food and split them up into smaller ones, which can pass through the intestinal wall and be carried to the tissue cells, where they are disposed of.

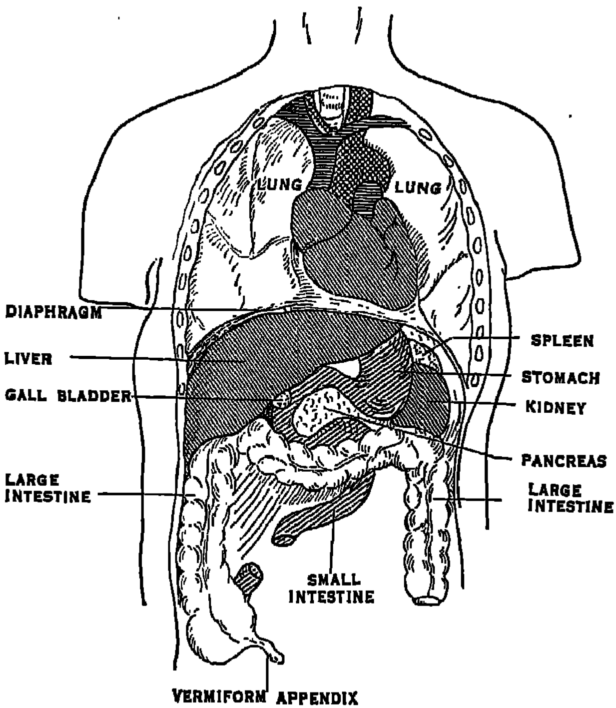


Fig. 19.3. The thoracic and abdominal organs. All but the upper part of the small intestine and the lower three inches or so where it empties into the large intestine have been omitted. The lower part of the large bowel including the rectum has also been removed.

Food lying in the digestive tract cannot truly be said to have entered the body. It is only in a tube surrounded by the body. Not until the food has been changed so that it is able to enter the blood and be used by the tissue cells can the body be said to have accepted it. The digestive tube—the stomach and intestines—are, as it were,

[5] Sometimes, undigested protein, such as raw egg white, passes in very small amounts into the blood; it is excreted practically unchanged in the urine.

the kitchens of the body's household, where food is prepared for the tissues.

The chemical changes in the food which the digestive juices accomplish consist mainly of splitting each molecule of the disaccharides and starches into their constituent glucose molecules, of breaking up the fat molecules into a molecule of glycerine and three molecules of fatty acid and, as mentioned above, of the disruption of the protein molecule into its several amino acids.[0] Only in these simple forms can the food be absorbed.

Let us for a moment enter a world that lies beyond our senses and try to form in our "mind's eye" a picture of what our knowledge tells us must be so. The lining of the digestive tract, though apparently free from any gaps or pores, is in reality pierced by millions upon millions of fine openings, like a sieve, though with a *mesh beyond the power of any ordinary microscope to discover.*

Molecules of food materials, such as those of glucose or water, which are smaller in diameter than the intestinal "mesh," can pass through with little hindrance. Larger molecules are barred. Here and there we may see these larger molecules as they lie in the intestine being shattered by the chemical processes of digestion into smaller ones, no larger than the mesh of the enclosing intestinal screen. If we took a sausage skin, which is the intestinal wall of a pig, and tied one end, filled it with salt and water, and partly submerged the little sac in a glass of pure water (Fig. 19.4), we should find that after a time the water in the glass had a salty taste. If we had filled the sausage skin with a solution of glucose instead of salt, we should have found that after a time the water in the glass had a faintly sweet taste. Evidently, then, the small molecules of salt or

[0] Some 23 different amino acids have so far been discovered. The more complex proteins contain nearly all of these different types. Others, such as gelatin, are called incomplete because they lack some of the amino acids which are essential for the promotion of growth or even of sustaining life. The amino acids are linked together in the protein molecule in the following way.

$$\underbrace{CH_3\cdot CHNH_2\cdot CO}_{\text{Alanine}}-\underbrace{HN\cdot CH_2\cdot COOH}_{\text{Glycine}}$$

The size and weight of the protein molecule depends upon the total number of amino acids of all types which compose it. The weights of some proteins are relatively small; others have weights over 1,000 times greater. The shapes of the molecules of different proteins are also variable; some are globular in form, others are long and slender—fiber-like in shape.

of glucose passed through the sausage skin into the surrounding water. If we were to fill the sac with white of egg or starch or fat and repeat the experiment, we should not find white of egg or starch or fat in the surrounding water. (See also p. 9.)

But it must not be thought that amino acids and other products of digestion pass through the intestinal wall by purely physical forces—e.g., diffusion and osmosis—as through a dead membrane. Absorption from the intestine is the result of living processes.

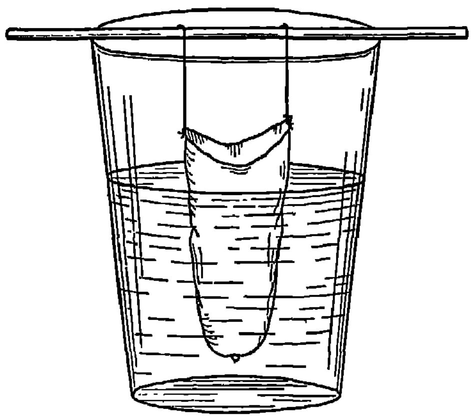


FIG. 19.4. Sausage skin containing sugar or salt solution and immersed in water. (See explanation in the text.)

The mucous membrane of the intestine, like the tubules of the kidney, shows a selective power which is lost after its death. Glucose, for example, which is utilized by the body, is absorbed much more readily than are other sugars which have no nutritional value.

The digested food is absorbed almost entirely from the small intestine. Neither food nor water is absorbed from the stomach, though alcohol can enter the blood from this part of the alimentary tract. Water, but little or no food material is absorbed from the large intestine.

The changes which digestion produces in the food are shown diagrammatically in Figure 19.5.

The reader may realize how wonderful is the digestion of food if he is told that a chemist, in order to carry out similar changes by the ordinary methods of chemistry, is forced to use powerful

agents, such as strong acids, or great heat. The food in the stomach and intestines undergoes chemical changes—that is, digestion—with the greatest ease. No great heat is required, and the chemicals used by the body in its laboratories—stomach and intestines—are com-

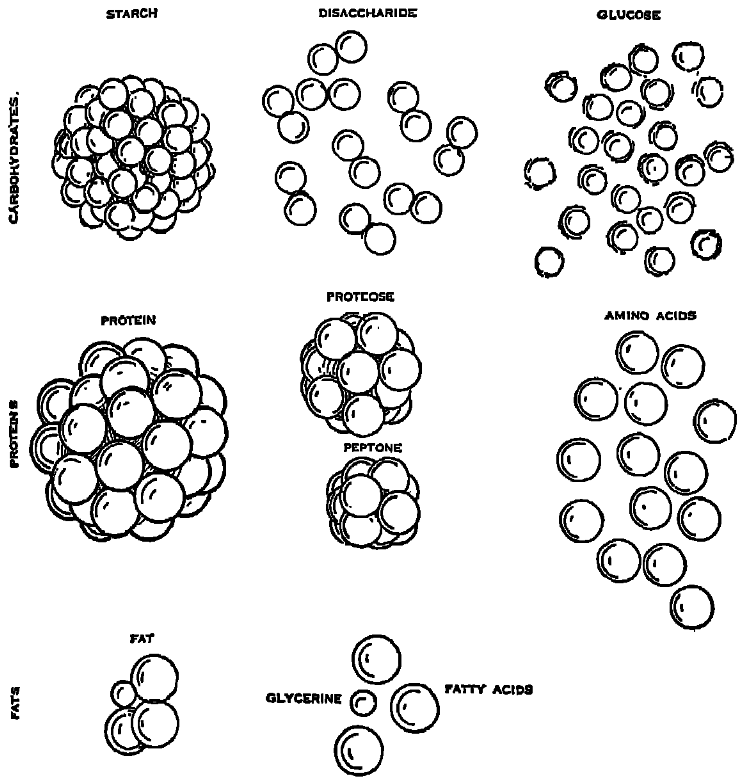


Fig. 19.5. Diagram to illustrate the constitution of the three foodstuffs—carbohydrates, proteins, and fats.

paratively mild. Yet even pieces of bone, if not too large, are digested in a dog's stomach.

When we eat a meal of roast beef, potatoes, bread and butter, and a glass of milk, we give little thought to the miracles which the laboratories of the stomach and the rest of the alimentary tract perform. We impose a task upon the digestive glands and their secretions which one skilled in the ways of chemistry and furnished

with the facilities of a modern laboratory could not perform so quickly or so well, if at all.

What enables the body, then, to do things which the chemist can do only very clumsily? The answer is that certain cells in the body have developed the power to manufacture substances called *enzymes* (p. 181), which act, each in its way, upon the different foods. The cells which form these substances are collected into groups called

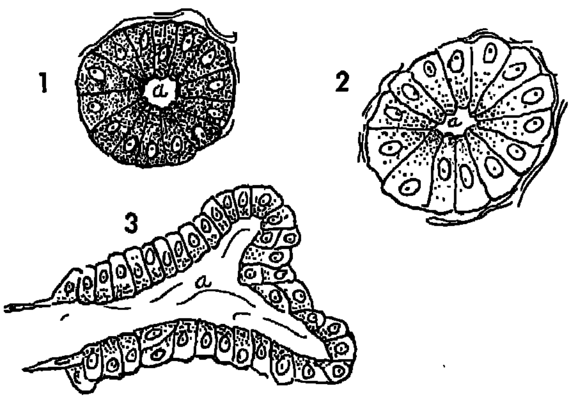


Fig. 19.6. Microscopic appearance of a typical gland. 1, the alveolus of a resting gland. The cells are loaded with granules from which the essential organic material of the secretion is derived. 2, an alveolus after a period of secretory activity; note that the granules are sparse and are completely lacking from the bases of the cells. *a*, cavity of the alveolus into which the cells discharge their secretion. 3, an alveolus sectioned lengthwise; the commencement of a fine duct is shown at the left.

glands. These cells also secrete water, in which the enzymes are dissolved, and various mineral salts. When a gland, such as the salivary, forms a juice and pours it out upon the food, it is said to *secrete*. Secretion is a very complex process and is far from fully understood. The cell of which a gland is composed selects from the blood, which flows through its fine vessels, the materials required for the manufacture of the several constituents of its juice. The enzymes, or the mother-substances from which the juice is finally produced, often may be seen microscopically in the cells of a resting gland as fine droplets or *granules* (Figs. 19.6 and 20.3). In this form the enzyme material is stored until required. When, as a result of nerve impulses or some chemical stimulant (*hormone*)

carried in the blood stream, the gland is caused to secrete, the granules become reduced in number or entirely disappear, for many, together with water and salts, have been forced from the cells into the cavity (or alveolus) of the gland. (See also p. 185.) The juice so formed is then carried along fine tubes, the *ducts* of the gland, into the digestive canal—e.g., mouth, stomach or intestine.

Enzymes, or *ferments* as they are sometimes called, are responsible for the chemical changes in the food which take place during digestion. The various digestive juices—salivary, gastric, and pancreatic secretions—contain different kinds of enzymes, each of which acts upon a particular type of food—carbohydrate, fat, or protein. The nature of enzymes, their wonderful ability to bring about chemical changes, and the manner in which they act have been problems of long standing.

Enzymes are responsible for many chemical reactions other than those of digestion. The work of the great Pasteur showed that several hitherto unexplained chemical processes were in truth due to their actions. The conversion of sugar and water into alcohol and carbon dioxide—alcoholic fermentation—is brought about by enzymes formed by the cells of yeast. An enzyme, also formed by living organisms, converts alcohol to *acetic acid*. The formation of lactic acid in the souring of milk is produced by a germ—the *lactic acid bacillus*. Microorganisms are also used in industry to produce, through enzyme action, chemicals which cannot be made in any other way.

These examples show that enzymes are not peculiar to the digestive systems of animals but belong to a class of substances known widely throughout nature. Like the cell of the yeast plant, certain cells of the animal body have learned the trick of manufacturing them. Such enzyme-producing cells constitute the tissue of the digestive glands mentioned above. In their general nature the enzymes of the animal body are essentially the same as the yeast or lactic acid ferments. It is only in detail—in the particular chemical changes which they accomplish—that the digestive ferments are different from these.

Many theories have been advanced in attempts to explain enzyme action. No theory is entirely satisfactory; yet several facts have been discovered. We know many things about the way an enzyme acts but not a great deal of the underlying causes of its action. Some of

the characteristic features of this action may be described. Just as a lever can move an object many times its own weight, so an enzyme can act upon and produce chemical changes in a mass of substance many, many times its own size and weight. "A little leaven leaveneth the whole lump." Another peculiarity of an enzyme is that it does not form part of the final product of the chemical reaction. It can be recovered practically unchanged after the chemical process for which it is responsible has come to an end. A digestive enzyme can act upon a food substance only when water and a certain amount of acid or alkali is present. Other enzymes require the presence of certain minerals—e.g., calcium, magnesium, potassium, etc. Such accessory substances are called *coenzymes.*

During digestion, the enzymes in some way bring together the molecules of water and the molecules of the foodstuff—fat, protein, or carbohydrate. The molecules of the food then break up into smaller ones. This process, in which a substance takes up water and then splits into simpler compounds, is called *hydrolysis.*

If you have studied chemistry, you will recall that certain inorganic substances in very small amounts act to speed up chemical reactions which without such action would proceed very slowly and sometimes almost imperceptibly. Substances of this nature are called *catalysts.* Thus, if a solution of cane sugar is left undisturbed for a long time a certain small amount of the disaccharide will be found to have become converted into hexoses (p. 170). If, however, a little hydrochloric acid be added to the solution, splitting of the cane sugar molecules proceeds much more rapidly. Only a small amount of the catalyst (hydrochloric acid in this case) is required and it remains itself unchanged by the reaction. Enzymes, since they act in very much the same way, might be called *organic catalysts*—i.e., catalysts formed by living organisms.

The action of an enzyme is speeded up when the temperature is raised and is slowed down when the temperature is lowered. Enzymes are destroyed by very high temperatures. The digestive enzymes, as might be expected, do their work best at the temperature of the body. Each enzyme is a specialist. In its own particular field it does its work well, but it is unable to take on any other duty. For instance, if it can digest starch, it is unable to digest protein or fat; if it can cause chemical changes in protein, it is worthless for splitting the molecule of fat or of sugar, and so

on. This characteristic makes one think of each enzyme as a key which will fit but one lock—a particular type of molecule.

Though the old names for certain of the digestive enzymes are still often used, such as *ptyalin* for the enzyme of the saliva, *pepsin* for the chief enzyme of the gastric juice, and *trypsin* for the enzyme of the pancreatic juice which acts upon protein, it has become more customary to coin a name for a particular enzyme by adding the suffix "ase" to the name of the substance upon which the enzyme exerts its specific action.[7] Thus, ptyalin acts upon starch; *salivary amylase* (L. *amylum* = starch) is, therefore, another name for this enzyme. An enzyme which acts upon protein is called a *protease;* so we have a *gastric* (pepsin) and a *pancreatic* (trypsin) *protease.* An enzyme which splits fat is called a *lipase.*

[7] The substance upon which an enzyme acts—e.g., starch, protein, or fat—is called the *substrate.*

chapter 20

DIGESTION IN THE MOUTH

The formation and composition of saliva.—The saliva is the first digestive juice with which the food comes into contact. Its digestive action, however, is confined to starchy food. The saliva is formed

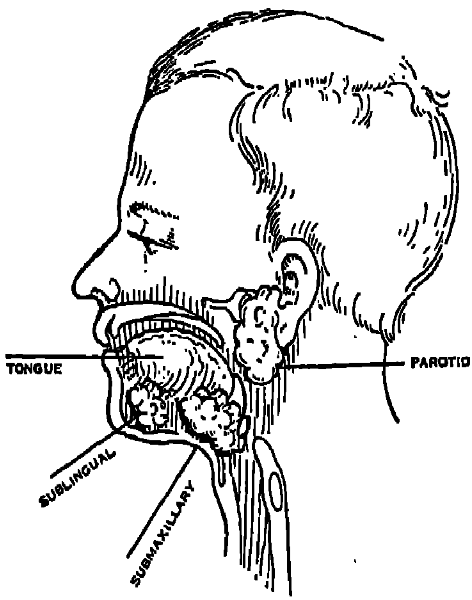


FIG. 20.1. The salivary glands of one side.

and secreted into the mouth by six separate masses of cells—three on each side—called the *salivary glands.* One of these, the *parotid* gland, lies below and in front of the ear and behind and partly overlapping the upper part of the lower jaw (Fig. 20.1). It becomes inflamed, swollen, and painful in mumps. The other two glands—the *submaxillary* and *sublingual* glands—lie in the floor of the

mouth beneath the tongue and within the concavity of the lower jaw. The individual cells of salivary glands are arranged according to a very definite pattern, which, of course, can be seen only under the microscope (Fig. 20.2). The somewhat wedge-shaped cells are in small groups. Each group is arranged around a central cavity called an *alveolus*. The cells form a secretion or juice, which is passed into the alveoli, and is then drained into the mouth through small ducts.

The duct system of the gland commences as microscopically fine tubes leading one from each of the many alveoli. The union of

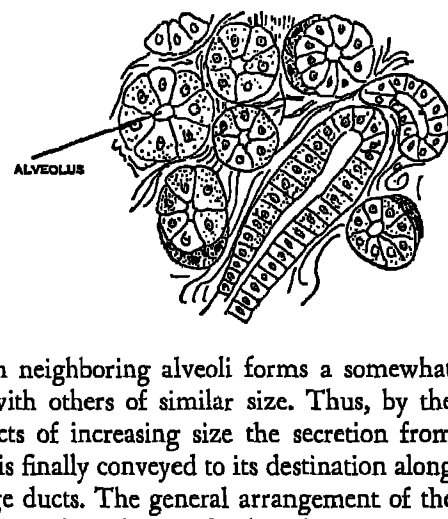


FIG. 20.2. Microscopic appearance of the salivary gland.

several such channels from neighboring alveoli forms a somewhat larger duct, which joins with others of similar size. Thus, by the successive junctions of ducts of increasing size the secretion from the numberless gland cells is finally conveyed to its destination along one or more relatively large ducts. The general arrangement of the ducts reminds one of the stem branchings of a bunch of grapes—each group of cells with its central alveolus corresponding to a grape (Fig. 20.3).

The saliva is over 95 percent water, in which are dissolved small quantities of the salts of sodium, calcium, potassium, and phosphorus and a ferment called *ptyalin*.

How saliva is secreted.—The secretion of saliva is always brought about through reflex action (p. 282). The reflex may be one of two types. For instance, saliva is secreted when food or other material enters the mouth and is tasted. The material may be pleasant to the taste or disagreeable; saliva is secreted in either case. Even materials with little or no taste may cause secretion. Irritation or in-

jury to the lining membrane of the mouth may also cause a flow of juice. The drilling of a tooth by the dentist often causes profuse salivation. This type of reflex, which results from direct stimulation of the organs of taste or of the mucous membrane of the mouth, is called an *unconditioned* or *inborn reflex*. In other instances a secretion of saliva occurs though no food or other material enters the mouth, and no stimulus whatever has been applied directly to

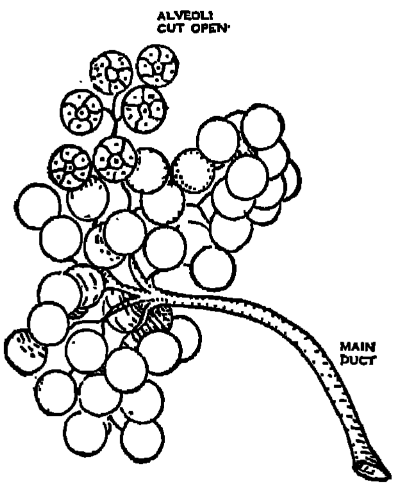


FIG. 20.3. The duct-alveolar system of a racemic type of gland (L. *racemus* = a bunch of grapes).

the lining of the mouth. For instance, the smell, the sight, the mention, or even the thought of food may, as we all know, "make the mouth water," especially when one is hungry. This type, which depends upon any one of the other senses—sight, smell, hearing, etc.—as well as upon previous taste sensations, is called a *conditioned, acquired* or *learned reflex.*

Conditioned reflexes. At the beginning of this century the Russian physiologist Pavlov carried out some interesting experiments upon dogs (Fig. 20.4), from which we have learned a great deal about the conditioned reflex. Pavlov performed his experiments in the following fashion. A dog was fed with appetizing food, and at the same time a bright white or colored light was flashed within view of the animal. The light was shown for several days each time the animal was fed. After a certain number of such trials, or lessons as they might be called, the light was shown, but the animal was

not fed. Nevertheless a profuse secretion of saliva occurred. The same remarkable result was obtained when, instead of a light being shown at the time of feeding, a note was sounded upon a horn, or a bell was rung, or the skin was stimulated by a weak electric shock. After the preliminary period of training, the sound of the horn or

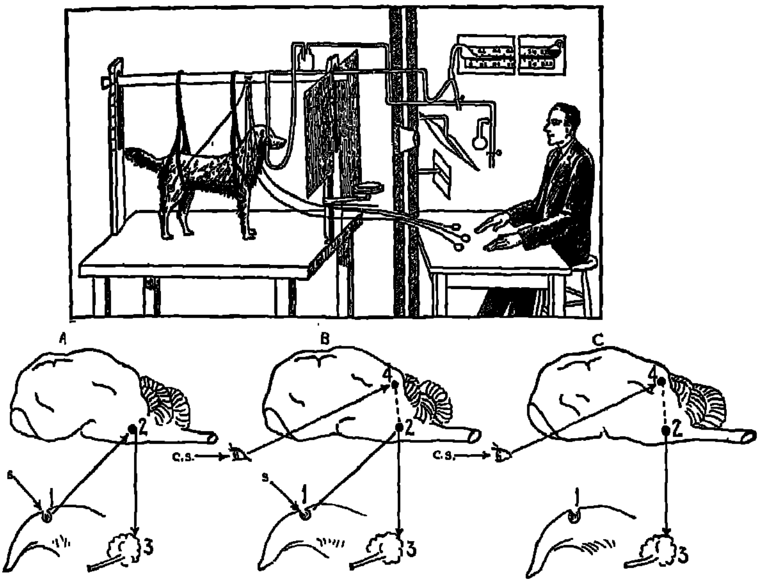


FIG. 20.4. *Upper drawing,* arrangement for carrying out a conditioned reflex experiment. The opening of the parotid duct has been transplanted to the skin of the cheek so that the saliva as it is secreted may be collected and measured. The animal is separated from the experimenter by a partition in order that extraneous types of stimulation (e.g., movements or sounds made by the experimenter) shall not arouse the animal's interest and thereby interfere with the conditioning process. (*From Pavlov, Lectures on Conditional Reflexes, International Publishers, N. Y.*) *Below,* diagram to illustrate the theory of the mechanism underlying conditioned reflexes. 1, taste buds; 2, salivary center; 3, salivary gland; 4, occipital (visual) cortex; *S,* unconditioned stimulus; *C.S.,* conditioned stimulus. In *A* the animal is fed and a stimulus thus applied to the taste buds. In *B* a conditioned visual stimulus (e.g., a flash of light) is applied at the same time as the unconditioned stimulus. A pathway from the occipital cortex to the salivary center is thus established. In *C* the conditioned stimulus is applied alone. Impulses pass from the visual cortex to the salivary center and evoke salivary secretion. The center for taste and its connections with the visual and salivary centers are not shown.

the bell or the sensation of the electric shock was sufficient alone to cause secretion. We would not think that a dog, however intelligent, could be capable of making a distinction between lights which differed slightly in color, or of distinguishing between musical notes of different pitch. Yet, when a light different in color from that used during the training period was shown at the time of the test, no secretion of saliva occurred. Similarly, a note only slightly higher or lower in pitch than the one employed during training was unable, when tested alone upon the animal, to cause any secretion. It was entirely disregarded.

In other instances a light was flashed or a bell rung two minutes or so before an animal was fed. This was repeated for a few days until the animal was trained. After this, when the same light was shown or the bell was rung, a secretion of saliva occurred—not immediately, but two minutes later almost exactly to the second—though no food whatever had been given.

These are all typical examples of conditioned reflexes. They are brought about through associations formed in the brain between sight, smell, hearing, touch or certain other sensations and the sense of taste. This implies that those parts of the brain where the sensations of sight, smell, hearing, etc., are recorded, are connected by nerve fibers with that part where are seated the memories of taste. This latter region of the brain must also be connected with those nerve cells which send secretory fibers to the salivary glands. Unquestionably the higher parts of the brain play an essential part, and intelligence and education are necessary for the reflex. The experimental examples just given, though less familiar to us, are really not greatly different from the conditioned reflex which causes the mouth to water when we ourselves see or smell appetizing food. We too, though we do not remember it, have been trained to associate in our minds the sight or smell of an article of food, its color, shape, etc., with its taste. Having formed this association, the smell or sight of the food alone is enough to cause secretion. Had we been blind and but recently regained our sight, or had we just acquired the sense of smell, the sight or smell of the most tempting morsels would not make the mouth water.

The precise pathways taken by the nerve impulses when a secretion of saliva occurs as a conditioned reflex are not known. But we may imagine, in a general way, their course. Let us say that secre-

tion has been caused by the sight of some appetizing food, or merely by a visual stimulus (such as a flash of light) which previously has been associated, during a period of "learning," with an agreeable taste. The impulses set up in the retinas are transmitted along the nerves of the eyes (optic nerves) to those parts of the brain where visual sensations are interpreted and recorded. They then pass (actually fresh impulses are set up), as in a groove or channel established by previous experience, along nerve fibers to the region where memories of taste are stored and from there to nerve cells (salivary center) in the hind-brain (medulla) from which the nerves to the salivary glands arise; or the impulses may take a more direct course, as shown in Figure 20.4, from the visual to the salivary center.

The digestion of starch by saliva.—The ptyalin (p. 185) of the saliva converts cooked starch into *malt sugar* or *maltose*. It has no action upon fats or proteins. Most starchy foods, before they can be attacked by the saliva or the other digestive juices of man, must be cooked. The potato, for instance, is made up of cells having an envelope of *cellulose,* and this material is indigestible. So long as the cellulose envelope remains unbroken, the enzymes cannot reach the starch in the interior of the cell. Raw potatoes, apples, wheat kernels, oats, etc., for this reason, possess little nutritive value for man. Yet, as we know, raw vegetable food is the sole source of nourishment for herbivorous animals. These species possess means for the digestion of cellulose. Man, on the other hand, must rely upon heat to rupture the cellulose envelope before he can assimilate foods composed mainly of starch. Steaming, boiling, roasting, etc., burst the cellulose envelopes of the cells and allow the enzyme to come into contact with the starch within.

The digestion of starch by ptyalin is carried out in a series of steps which can be detected by suitable chemical means. If a little boiled starch and water is mixed with saliva in a test tube and the mixture kept warm, after a short time the starch will be found to have become more freely soluble. It then is called *soluble starch.* This, like the unchanged starch, gives a blue color when a drop of iodine is added to it. Later the soluble starch is converted into *dextrins,* which are *polysaccharides* possessing a smaller number of glucose molecules than the original starch. The dextrins are of two kinds. The one formed first gives a brownish-red color with

iodine. It is therefore called *erythrodextrin* (Gk. *erythros* = red). The second gives no color with iodine. This colorless dextrin is called *achroödextrin.* Later the dextrin turns to *maltose,* a sugar belonging to the class of *disaccharides* (p. 170). The ptyalin has little or no power to carry the digestion of starch beyond the maltose stage. The steps in the digestion of starch by ptyalin are shown in the following table:

Boiled starch	Blue color with iodine
↓	
Soluble starch	Blue color with iodine
↓	
Erythrodextrin	Red color with iodine
↓	
Achroödextrin	No color with iodine
↓	
Maltose	

Since the food is but a very short time in the mouth before it is swallowed, the enzyme of the saliva has little or no action upon it there. If, however, the food has been well chewed and thoroughly moistened with saliva, conversion of a large part of the starch into maltose may occur while the food lies in the stomach. But even so, maltose cannot be absorbed into the blood. Its molecule must first be split into its two glucose constituents before the digestion of starch can be said to be complete. The maltose, as well as any starch that has not been converted to maltose, must remain to be digested by the digestive juices of the intestine (Chap. 22).

Other functions of the saliva.—The digestive action of the saliva is probably of much less value than some of its other functions. Of greater importance is its use for moistening the food, rendering it plastic, and so enabling it to be easily swallowed. The saliva permits perfectly dry food to be eaten. We all know that, even though our salivary glands secrete freely, it is not always easy to swallow a dry biscuit, and sometimes it is necessary to drink water or other fluid in order to aid the passage of other dry food into the pharynx and esophagus. Without saliva or some fluid to take its place, it would be impossible to swallow food which is perfectly dry. A man, in the course of a day, secretes a surprising

amount of saliva. Something like a pint and a half of fluid is poured into the mouth by the salivary glands in this time. A cow, eating dry fodder, secretes 2 to 3 quarts in 24 hours.

Saliva also helps to keep the mouth clean and fresh. Food particles which otherwise would lodge upon the teeth, gums, and tongue are being constantly flushed away by the saliva, which is kept in motion by the actions of the tongue, lips, and cheeks. In keeping the soft parts of the mouth moist and pliable the saliva plays a very important role in the mechanisms of speech. It is almost impossible to speak plainly if the mouth is dry. Many public speakers must sip water occasionally during a speech or lecture, because sometimes evaporation of moisture from the mouth is so great that the saliva alone is insufficient to keep the parts soft and freely movable. In certain fevers, notably typhoid, the salivary secretion is suppressed, with the result that the mouth becomes very dry and the tongue and lips become hard and cracked. Food tends to collect upon the tongue and teeth and in the folds and crevices of the mouth. The mouth would soon become very foul unless measures were taken to prevent it. To overcome this unhygienic state, the nurse cleans the interior of the mouth frequently with a swab of gauze soaked in a mild antiseptic solution, such as boric acid. Drying of the mouth arouses the sensation of thirst, so that anything which tends to reduce or suppress the secretion of saliva will make one thirsty. Acid-tasting materials, such as lemons, oranges, and grapefruit, stimulate the secretion. Fruits and fruit-flavored drinks owe their refreshing and thirst-quenching qualities largely to this fact. The action of the saliva in dissolving various substances is also almost essential to the sense of taste. Sugar, salt, and many other substances must be in solution before they can be tasted.

Many substances are excreted from the blood into the saliva; among these are certain drugs, such as mercury, iodides, lead, etc. The germs of several diseases, such as hydrophobia, infantile paralysis, and mumps, also pass from the blood into the saliva. Infantile paralysis has been reproduced in monkeys by injecting them with the saliva of an infected person. It is apparent, then, that diseases may be easily transmitted from one person to another through particles of saliva clinging to eating and drinking utensils, by kissing, from dried saliva that has been expectorated and blown about

as dust, or even by talking to a person infected with influenza or other diseases. During the act of speaking, saliva, in the form of fine invisible particles, is cast from the mouth for a distance of several inches.

The saliva contains important salts—calcium, potassium, sodium, etc. Under ordinary circumstances these are not lost to the body, since the saliva is swallowed, and the salts are re-absorbed. A person who is continually spitting practices a habit which is not only offensive and endangers the health of others, but which, through the loss of valuable salts, is unwholesome for the individual himself.

chapter 21

DIGESTION IN THE STOMACH

The form and structure of the human stomach.—The human stomach, when empty of food, is a long, collapsed tube (except for its upper end) lying almost vertically in the upper part of the abdomen, or sometimes sloped down and to the right at an angle of about 45 degrees. Its upper blind end is dome-shaped and lies below the apex of the heart, separated from it by a part of the liver and the diaphragm. This part of the stomach contains a few ounces of trapped air or gas which inflates it. A little below and to the right of the upper end of the stomach is the opening of the gullet or esophagus. The lower part of the stomach is usually the shape of the letter J or of a fishhook and lies partly to the right of the mid-line of the body at about the level of the navel (*umbilicus*). If a person is given a mixture of barium and his abdomen then X-rayed the stomach will cast a shadow picture upon a sensitive film, because barium is opaque to the X rays. Such pictures have shown that the older descriptions of

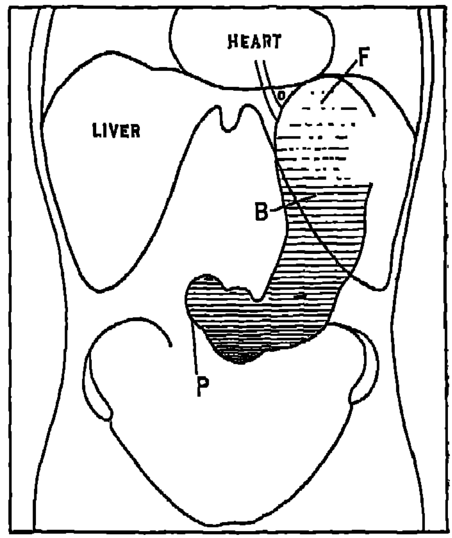


Fig. 21.1. Appearance of the stomach by X rays. *F*, fundus; *B*, body; *P*, pylorus. (*Redrawn from Starling.*)

the position and shape of the stomach, as a rounded, somewhat pear-shaped bag lying more or less horizontally across the abdomen, were wrong. Of course, the shape of the stomach and the position of its lower part changes from time to time with the degree to which it is filled with food.

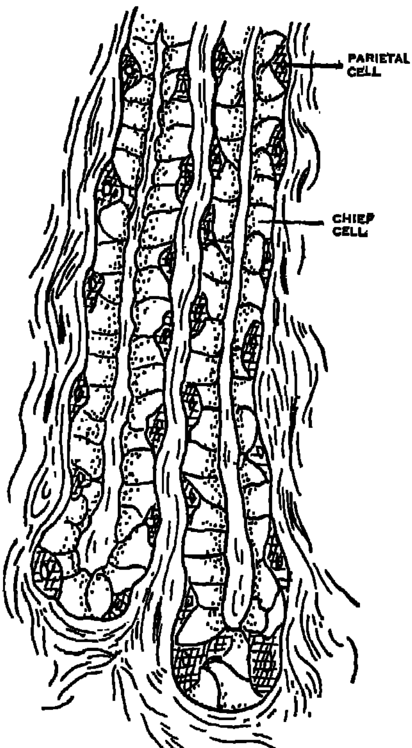


FIG. 21.2. Two gastric tubules showing the two main types of secreting cells.

The lower part of the stomach—that portion corresponding to the hook of the J—is called the *pyloric part*. The opening through which the food passes from this part into the intestine is called the *pyloric orifice*, or simply the *pylorus*. The rounded upper part of the stomach is known as the *fundus*. The opening of the esophagus into the stomach is called the *cardia* or cardiac orifice. The middle or main part of the stomach is called the *body*.

The glands of the stomach.—The cells which secrete saliva, we have seen, are massed together into six large glands, which deliver their secretions into the mouth along a few large ducts. The *gastric glands*, on the other hand, are innumerable. They lie in the lining of the stomach, which is called the *gastric mucosa*. Each gland consists of a minute tube not as thick as a hair, buried in the wall of the stomach and opening by a small mouth upon the surface of the mucosa. Each little tube is lined by cells which secrete the juice containing the enzymes. This is known as the *gastric juice*. The glands of the stomach have no branching system of ducts like the salivary glands and the pancreas. There are millions of these tiny tube-like glands each with its own small

mouth. The secretion, as it is formed, is passed directly into the cavity of the stomach.

The secreting cells are of two kinds. One type of cell (*chief cell*) forms the pepsin of the gastric juice, and the other (*parietal* or *acid cell*) forms the acid (Fig. 21.2). Only the glands in the mucosa of the fundus and body of the stomach possess acid-secreting cells. The glands in the pyloric part of the stomach have no cells of this type and so do not form acid. The pyloric glands secrete, instead, a slimy juice which is composed chiefly of mucus and contains little if any pepsin.

The Composition of the Gastric Juice

The juice secreted by the gastric glands contains the following substances:

$$\text{Enzymes}\left\{\begin{array}{l}\text{Hydrochloric acid}\\ \text{Pepsin}\\ \text{Rennin}\\ \text{Lipase}\end{array}\right.$$

Pepsin.—*Pepsin* is an enzyme formed by the chief cells of the gastric glands. It has the power to carry the digestion of protein food through the first stages toward its final breakdown. The large groups of amino acid molecules of which protein is composed are broken into smaller groups (Fig. 19.5). The smaller groups of amino acids formed when protein is acted upon in this way are called *proteoses* and *peptones*. The proteoses are composed of larger groups of amino acids than the peptones, and are the first fragments into which the protein molecule is broken by pepsin. Peptones are formed at a somewhat later stage of gastric digestion. These substances are quite different from the original protein. They can, for instance, be dissolved in water, and, since the molecules are somewhat smaller, they can pass through some animal membranes. Nevertheless, they cannot nourish the body unless further digested.

When the action of enzymes was described (p. 181), it was stated that some of these required the presence of acid, others of alkali, before they could perform their allotted tasks. Pepsin is one of those enzymes which can act only with the aid of acid. The hydrochloric acid is formed for this purpose and secreted with the pepsin.

The origin of the hydrochloric acid.—Hydrochloric is a strong mineral acid. In full strength, as you know, it will dissolve small particles of iron, zinc, and other metals. If dropped upon the skin, it will burn painfully. It came as a great surprise, then, when this powerful chemical, which under ordinary circumstances is so injurious to living tissues, was discovered to be a constituent of the gastric juice. It is an extraordinary fact that such an acid should be manufactured by living cells. The only other instances of a strong mineral acid being formed by living processes is the production of sulfuric acid, probably for defense purposes, by certain mollusks, and the presence of acid within the body cavities of certain one-celled creatures (*protozoa*). The idea was so novel that in the past some physiologists were disinclined to believe that hydrochloric acid was actually formed by the cells of the gastric glands, and several experiments were performed to ascertain whether or not it was true. As a result of these experiments the fact is established beyond dispute that the so-called acid cells of the glands are little laboratories, which, taking the chloride of the blood as their raw material, produce large quantities of acid, which they then pour into the cavity of the stomach. Pure gastric juice contains from 0.4 to 0.5 percent of acid.

If a piece of meat is placed in a test tube with gastric juice or a solution of pepsin and hydrochloric acid, after a short time the meat will be found to have become dissolved. Conversion of the protein to proteoses and peptones has occurred. Yet the wall of the living stomach, which is composed chiefly of protein, is unaffected by the pepsin and hydrochloric acid of the gastric juice which it secretes. Why is the stomach not digested like any other meat? That is a difficult question to answer. All that can be said is that the living and healthy gastric tissue in some way is able to protect itself from the action of the gastric juice. On the other hand, if, as a result of injury or through the cutting off of its blood supply, a small area of the stomach loses its vitality, then this part of the gastric tissue may undergo digestion by the mixture of pepsin and hydrochloric acid secreted by the rest of the stomach.

Rennin or rennet.—This enzyme clots or curdles milk; it is secreted by the same cells which secrete the pepsin. It is used a great deal commercially to curdle milk in the manufacture of cheese. It is obtained for this purpose by grinding up the lining of the calf's

stomach and extracting the ferment with glycerine and water. The same ferment is employed for making junket.

Lipase.—This is a general term applied to ferments which digest fats. The lipase of the gastric juice—*gastric lipase*—is very weak, and ordinary fats and oils cannot be digested at all in the stomach. Certain fatty materials, such as the yolk of egg or cream, that are in the form of very fine emulsions, undergo a certain amount of digestion by the gastric juice, but the great bulk of the fat in the food is digested in the intestine. It passes through the stomach unchanged chemically, though physically it is liquefied to a larger extent into oil by the heat of the body, the separation of the fat cells by the digestion of the fibers binding them together, and by the churning movements of the stomach.

It may be concluded from the foregoing account of the action of the gastric juice that the chemical changes which the food undergoes in the stomach are chiefly concerned with the digestion of protein. However, as a result of the movements of the stomach (p. 216) and the addition of the fluids secreted by the gastric glands, swallowed as beverages, and secreted as saliva, all foods, whatever their nature, also undergo certain physical changes. Softening, liquefaction, or solution of the food occurs until, at the end of gastric digestion, the contents of the stomach are semi-fluid, having the consistency of gruel or thick cream. The food in this state is spoken of as *chyme.*

The Secretion of Gastric Juice

Food stimulates the gastric glands to secrete juice. Yet it has been known for many years that it is not necessary for the food to enter the stomach in order for the glands to be stimulated. The mere presence of food in the mouth will alone cause a very abundant secretion of gastric juice. The glands anticipate, as it were, the arrival of the food. The flow of juice which occurs under these circumstances is brought about reflexly (p. 282)—that is, through afferent impulses from the organs of taste to the medulla and from the medulla by the vagus nerves to the gastric glands. The flow of juice which is produced in this way is called the *psychic secretion.* It is also well known that gastric juice is secreted by means other than through nerve impulses, for the stomach secretes juice even

though all communication with the nervous system is cut off; the nerves, for instance, may be divided, yet the stomach continues to secrete juice when it receives food. This type of secretion which occurs only if the food actually enters the stomach, is termed, for the lack of a better designation, the *secondary secretion* or the *gastric phase* of the secretion of gastric juice.

The psychic phase of gastric secretion.—The psychic phase has been studied in animals by Pavlov. From the foregoing paragraph it is clear that, in order to study the psychic secretion, food must be given for the animal to chew, but the stomach should not receive it. If the food entered the stomach, it would be impossible to distinguish the psychic from the gastric phase. The animal is accordingly "sham fed," that is, the esophagus is divided in the neck. The part above the division is then brought out through the neck wound and stitched into position. An animal prepared in this way can eat and enjoy its food (Fig. 21.3), but no food enters the stomach after being swallowed. It escapes from the opening in the neck. The animal eats with relish, yet it never becomes satisfied, and so "sham feeding" can be continued for any length of time, and large quantities of gastric juice are secreted into the stomach when the animal is fed in this way. Even five minutes of sham feeding will cause the production of several ounces of strong gastric juice. The greatest quantity of juice is secreted for meat and other foods for which the animal is eager, because the essential quality of the food which causes the secretion is its palatability—not its chemical or physical properties. A greater secretion occurs if the animal is hungry. In contrast to salivary secretion (p. 185), disagreeable substances, such as acids, pepper, or inedible materials do not cause a secretion of gastric juice. Indeed, if juice is already being secreted, it may cease when some unpleasant substance is placed in the mouth.

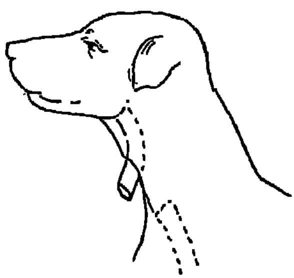


FIG. 21.3. A dog with an esophageal fistula made for sham feeding experiments.

These observations point to the involvement of mental processes in the reflex mechanism. The pleasure of eating, the agreeable stimulation of the organs of taste, and the gratification of appetite are

essential conditions. It is not even necessary that the food enter the mouth in order to cause the glands to respond. Provided the food is sufficiently appetizing, the mere sight or smell of it will cause secretion. In other words, a conditioned reflex occurs for the secretion of gastric juice as for the secretion of saliva. The stomach "waters" as well as the mouth at the sight or smell of food (p. 186).

Experiments similar to those described above have been carried out upon man. A man, of course, cannot be "sham fed" in the manner described above, but occasionally a person is found who has a closed esophagus. Usually this is the result of his having swallowed an acid or other destructive substance in childhood, which has so injured the gullet that a scar has formed during healing and completely closed the tube. No food can then pass into the stomach. It is necessary, therefore, for the person to be operated upon and for an opening to be made through the abdominal wall into the stomach through which he can be fed. Experiments upon such human subjects have shown that the principles discovered by Pavlov from his studies upon animals also hold true for man. Chewing food, or the sight or smell of an appetizing meal, causes a secretion of juice. The quantity of secretion is decidedly less if the food is unappetizing, or if the appearance and environment of the meal is unattractive. Offensive odors, worry, and anxiety are especially likely to depress secretion.

All these facts have their obvious applications to dietetics. Food agreeable to the palate and attractive in appearance, impressions received from a meal that has been prepared in a pleasing way, and probably, also, sensations aroused by the surroundings, yet not directly concerned with the food itself (music, good lighting, flowers on the table, etc.), all have an effect, especially in educated and cultured persons, upon gastric secretion. The impulse which guides the gourmet is sounder physiologically than that which impels the glutton. In planning a meal, the question of calories and of the relative digestibility of the different foodstuffs should not be allowed to obscure entirely the psychic elements in digestion, for the "delights of the table" have true digestive value. These facts are expressed in the phrase of Pavlov, "Appetite spells gastric juice," or in the hospitable words of Macbeth, "Now, good digestion wait on appetite, and health on both!" Custom seems to have discerned this truth, for it has decreed that the meal shall commence and end

with the more strongly flavored and appetizing morsels. For these reasons it is not always wise to force a child to eat something which is "good for him" but which he detests.

The gastric phase of gastric secretion.—The psychic secretion ceases within one to three hours after the last morsel of food has been swallowed. There has never been any question, however, that gastric secretion continues for a much longer period than this under ordinary circumstances—that is, when the food enters the stomach and undergoes digestion. How is this secondary secretion brought about? It is not governed by nerves, since it occurs after all the nerves to the stomach have been severed. The glands are stimulated to a mild degree by distention of the stomach—i.e., by the stretching of the stomach wall by the food. But the chief mode of stimulation is chemical. The chemical substance, or hormone (pp. 180 and 400) is formed in the wall of the stomach and carried to the glands in the blood stream. Certain materials in the food stimulate the stomach wall to produce the hormone. These materials are present in meat and in many vegetables; since they can be extracted with cold or hot water, they are called *extractives*. When meat is boiled, the water or broth is rich in extractives. Soups, beef teas, etc., consequently contain large quantities of these substances. Extractives possess no nutritive value; but, since they cause the formation of the gastric hormone which stimulates the gastric glands, they are important aids to digestion. For this reason the wisdom of starting the meal with a broth or a soup is self-evident.

Much experimental work has been undertaken in efforts to discover the nature of the gastric hormone. When it was first shown that an extract of the stomach wall caused a secretion of gastric juice when injected into the blood stream of an animal the unknown stimulating substance was called *gastrin*. Most physiologists now believe that the hormone is *histamine* (p. 113), a substance which, when injected, causes a profuse secretion of gastric juice. Histamine can be obtained in relatively large amounts from gastric mucous membrane and in variable amounts from many other tissues.

Fats depress the gastric phase; carbohydrates have little effect upon it one way or the other.

chapter 22

DIGESTION IN THE INTESTINES

The small intestine is the most important part of the alimentary canal, for here the main tasks of digestion are performed. About 5 percent of normal persons secrete no gastric juice, yet digest their food quite well and remain healthy. Sometimes as a result of disease it is necessary for the surgeon to remove the stomach, and yet digestion may be carried out without much difficulty. Another reason why the intestine is of so much greater importance than the stomach is that practically no food is absorbed into the blood from the stomach. In the intestinal walls are the only "doorways" through which nourishment enters the body.

Three juices are secreted into the small intestine—the *pancreatic juice,* the *bile,* and the *intestinal juice.* The chyme, upon leaving the stomach and entering the intestine, becomes mixed with these three juices, which carry the digestion of the food to its final stages.

The Pancreatic Juice

The pancreas.—The pancreatic juice is secreted by a gland which lies against the outer surface of the *duodenum*—the name given to the first 12 inches or so of the intestine (Fig. 22.1). This gland, known as the *pancreas,* has sometimes been called the salivary gland of the abdomen, because its microscopical appearance has a certain resemblance to the structure of the salivary glands. Also, like at least one pair of these glands, it lies outside the cavity of the alimentary tract into which it discharges its secretion through a long duct—the *pancreatic duct.* Besides its digestive function the pancreas manufactures insulin (p. 237). But this hormone passes, not into the intestine, but directly into the blood (Fig. 22.2).

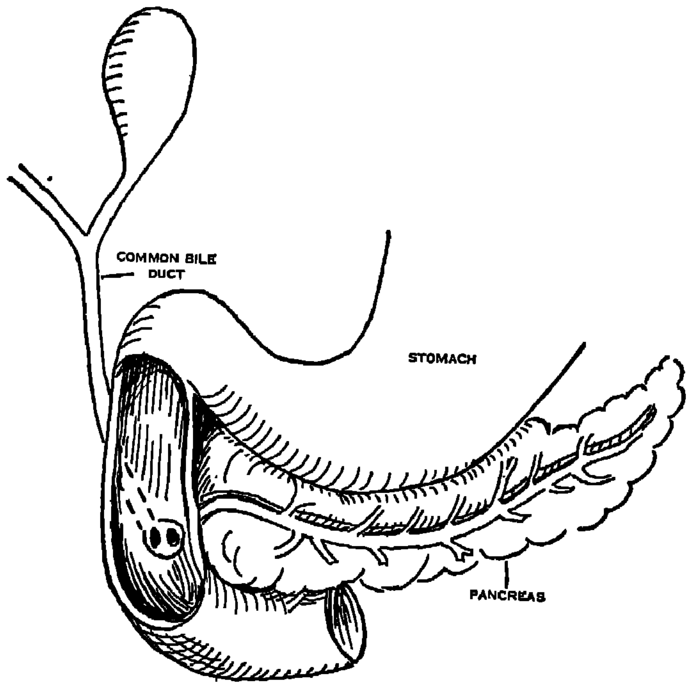


FIG. 22.1. The pancreas. The duodenum has been cut open to show the openings of the pancreatic duct and the common bile duct.

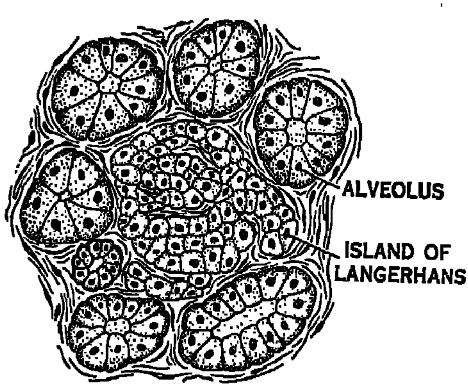


FIG. 22.2. Microscopic appearance of a section of the pancreas. An island of Langerhans is depicted surrounded by the alveoli which secrete pancreatic juice. Certain cells of the islands are the source of insulin.

The composition of pancreatic juice.—Pancreatic juice is composed of the following:

Enzymes	Trypsin Amylopsin Steapsin Rennin
	Sodium carbonate and sodium bicarbonate

All the enzymes of pancreatic juice require alkali for their action. This is provided by the sodium carbonate and bicarbonate which it contains.

Trypsin, or *pancreatic protease,* like pepsin, acts only upon proteins but carries the digestion of these a stage further. It splits the amino acid groups of the proteoses and peptones (p. 179) into still smaller groups, called *peptids.* The groups, after tryptic digestion has come to an end, may consist of only four, three, or two amino acid molecules bound together.

Amylopsin or *pancreatic amylase* resembles the ptyalin of saliva in its action; that is, it breaks the large molecules of starch into the smaller molecules of maltose (p. 190). But it is many times more powerful than ptyalin. As a matter of fact, it is not until starch reaches the intestine and is acted upon by the amylopsin of the pancreatic juice that it is effectively attacked. Maltose, we have already seen, is not absorbed, since its molecule is composed of two molecules of glucose. The pancreatic juice contains a weak ferment, *maltase,* which effects the final splitting of a small proportion of the maltose. The great mass of this sugar, however, is converted into glucose by a ferment in the intestinal juice.

Steapsin splits fat into *fatty acids* and *glycerine* (Fig. 19.4). In this action, it is aided, as we shall see, by the bile.

Rennin has the same action as the rennin of the gastric juice. It curdles milk.

The secretion of pancreatic juice.—The vagus nerve sends branches to the pancreas, and along these nerves messages flow from the involuntary nervous system (p. 313) to the gland and cause it to secrete. This, however, is only one means by which the secretion of the pancreas is governed. It is also stimulated by a hormone which is manufactured in the mucous membrane of the intestine and then carried by the blood to the gland. This hormone

is called *secretin*. If the wall of the intestine of any animal is ground up with water and then filtered so as to free it of solid particles, the clear fluid so obtained will be found to contain large amounts of secretin; for, when the fluid is injected into the blood of another animal, a very abundant secretion of pancreatic juice results.

Another hormone which stimulates the secretion of pancreatic juice has been discovered recently. It is called *pancreozymin*. Whereas secretin induces mainly the secretion of the water and salts of the pancreatic juice, pancreozymin stimulates chiefly the secretion of the enzymes.

The Bile

The secretion of bile.—The bile is secreted by the liver, the largest gland in the body. The liver lies in the upper part of the abdomen

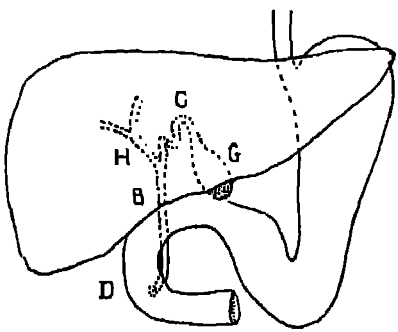


FIG. 22.3. The liver and gall bladder and their relation to the stomach. *B*, common bile duct; *C*, cystic duct; *D*, duodenum; *G*, gall bladder; *H*, hepatic duct.

and is molded to the undersurface of the diaphragm. The stomach is applied to the left third or so of its undersurface. The bile is drained away from the liver by a tube known as the *hepatic duct*. In man and most animals the secretion of the liver does not enter the intestine immediately but, after passing down the hepatic duct, is carried up another duct known as the *cystic*, which opens into the hepatic duct at an acute angle. By this union of the hepatic and cystic ducts a third, thicker tube is formed which conveys the bile into the duodenum; this is the *common bile duct*. The three ducts are thus arranged somewhat in the form of a Y. From the other end of the cystic duct there arises, like a pear upon its stem, a small sac called the *gall bladder* (Fig. 22.4). In it the bile is con-

centrated, for a large part of the water and salts of the bile is absorbed through the wall of the sac. Thus the bile is stored in concentrated form until required. The gall bladder contracts at variable intervals which are dependent upon the quantity and type of food undergoing digestion, and forces bile down the cystic duct and then through the common bile duct into the duodenum.

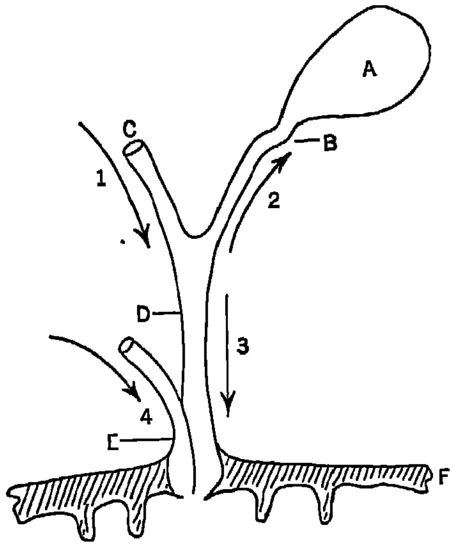


FIG. 22.4. Diagram of the biliary duct system. *A*, gall bladder; *B*, cystic duct; *C*, hepatic duct; *D*, common bile duct; *E*, pancreatic duct; *F*, intestinal wall. Arrow 1 shows direction of bile flow from the liver; 2, the flow to the gall bladder; 3, the flow down the common bile duct to the intestine; 4, the flow of pancreatic juice.

Strictly speaking, bile is not a digestive juice at all, for it possesses no digestive enzymes. It contains, however, certain substances, the *bile salts*, which aid the steapsin (p. 203) of the pancreatic juice in the digestion and absorption of fats. So important is this assistance given to the pancreatic juice that when, as sometimes happens, the duct becomes obstructed and the bile is prevented from reaching the intestine, the digestion and absorption of fat are very incomplete. Oils or fatty food, such as cream, etc., excite the gall bladder to contract and expel its contents. Thus nature has provided that since bile is necessary for the digestion of fat, fat causes bile to enter the intestine.

The pigments of the bile.—The bile contains two pigments—***bilirubin*** and ***biliverdin***. Bilirubin has a golden-red color; biliverdin is yellow-green. The pigment of human bile is mostly bilirubin, whereas the bile of cattle and birds is chiefly biliverdin. Both pig-

ments have the same origin. When bilirubin becomes oxidized, it passes through a series of color changes, and the first change is to green, that is, to biliverdin.

The bile pigments are derived from the hemoglobin of the red cells. We have already seen (p. 37) that each day millions of red cells die and are replaced by fresh ones turned out by the bone marrow. The dead or dying cells are seized by huge cells found in the spleen and in other places—e.g., the liver, bone marrow, and the general connective tissues. These cells, which belong to the reticulo-endothelial system, "mine" the hemoglobin for the valuable iron in its molecule. The hemoglobin, thus deprived of its iron, is passed on to the liver cells, where it is excreted in the bile as bilirubin, or as the latter's oxidation product, biliverdin. The iron is stored in the liver and spleen and used later from time to time for the manufacture of new hemoglobin.[1]

We have all observed the series of changes in color through which a bruise passes. At first the skin appears a dark red color or almost black. After a few days the bruise becomes lighter and acquires a greenish blue hue, later a yellowish green, then a yellow, which finally disappears. The color sequence is due to bilirubin and its oxidation products. This is what happens: An injury to the surface of the body, particularly where the tissues are soft and loose, causes the rupture of some small veins lying perhaps at some little depth from the surface. Blood escapes and after a time makes its way to the surface and shows through the semi-transparent skin. The blood at first is dark because the reduced hemoglobin has not yet been changed by the large cells of the tissues mentioned above; but after a time the iron is removed, and bilirubin is formed. Oxidation of the pigment and its gradual removal account for the changes in the tint and depth of the color which result as time goes on. In a bruise, then, we can see before our eyes the formation of bile pigment. From the hemoglobin of millions of red cells which break up every minute in the healthy body small amounts of bilirubin are formed, which, carried by the blood to the liver, are excreted in the bile.

[1] When the bile reaches the intestine the bilirubin and biliverdin are acted on by bacteria and undergo reduction again. Their color changes to a deep yellow or brown. This pigment colors the feces and is called *stercobilin*. When the bile is prevented from reaching the intestine as a result of obstruction of the common bile duct the feces are pale and almost colorless.

Jaundice.—This is the term given to the yellow color of the skin, mucous membranes, and whites of the eyes which is seen when the blood contains too much bile pigment. Should the duct which carries the bile into the intestine (common bile duct) become completely blocked, as by a gallstone, then, of course, the pigment,

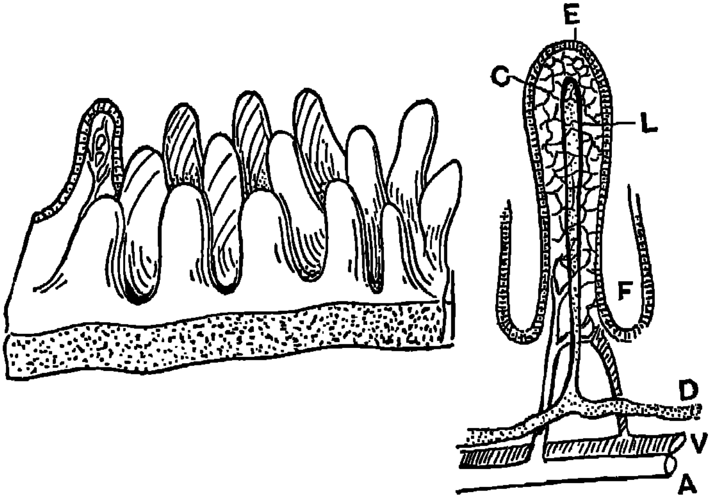


FIG. 22.5. *Left,* a group of intestinal villi (magnified). *Right,* section of a villus. *A,* small artery; *C,* capillary network; *D,* lymphatic; *E,* surface epithelium; *F,* crypt of Lieberkühn; *L,* lacteal; *V,* small vein.

which should be removed from the blood in the bile, accumulates within the body and stains the tissues yellow.

THE INTESTINAL JUICE

The lining of the small intestine, when looked at through a strong hand lens, appears covered with tiny fingers or very slender fleshy pillars called *villi* (singular = *villus*). Between these projections are minute wells or pits. These narrow wells, known as the *crypts of Lieberkühn,* are lined by cells and constitute the glands which secrete the intestinal juice (Figs. 22.5 and 22.6). The term *intestinal juice* is applied only to the secretion of these glands and is not used in a general sense to mean simply the fluids in the

intestinal canal. The Latin name *succus entericus* is also sometimes applied to the secretion.

The intestinal juice contains the following enzymes:

Erepsin
Maltase
Lactase
Sucrase
Lipase

Erepsin is a very powerful enzyme which attacks the fragments of the protein molecule after its digestion by the trypsin of the

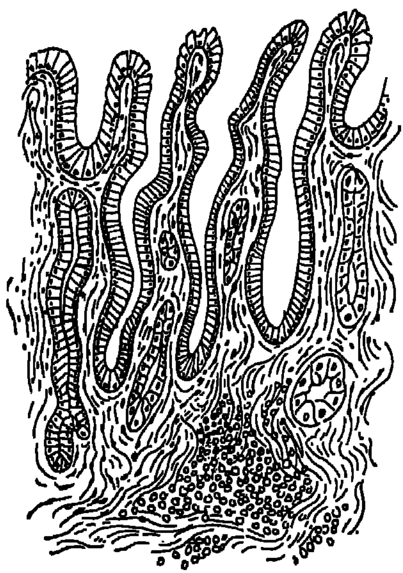


Fig. 22.6. Microscopic appearance of the wall of the intestine. Intestinal juice is formed by the cells lining the narrow pits. The narrow projecting fingers are the villi, cut through their centers.

pancreatic juice. Erepsin separates the individual amino acids from one another and so carries the digestion of protein to its final stage. The separate amino acids are absorbed into the blood and are carried to the many cells of the body, where they may be built up into protoplasm to repair the "wear and tear" of the tissues or for growth.

Maltase splits the sugar maltose into two glucose molecules.

Lactase, in the same way, splits lactose into two hexose molecules (p. 170)—glucose and galactose.

Sucrase acts upon cane sugar, breaking the molecule of this disaccharide into its constituent hexose molecules—glucose and fructose. No digestion of this sugar occurs until it reaches the intestine and comes into contact with the sucrase of the intestinal juice.

Lipase splits the molecules of fat into its constituents—glycerine and fatty acids.

In the diagram on page 179 the digestion of protein, carbohydrates, and fats is summarized.

Absorption of the Food

Food, whether carbohydrate, fat, or protein, if thoroughly digested, is practically all absorbed. Little, if any, is excreted from the intestine. The absorption occurs entirely through the intestine; not even water passes through the wall of the stomach. The small fleshy fingers mentioned above, and referred to as villi, are the elements responsible for the absorption process. Running through the center of each villus are a capillary, a small vein, and a lymphatic vessel. The latter is called a *lacteal,* since after a meal of fat it is filled with a milky fluid, which, seen through its walls, gives it a white and glistening appearance. Water and the soluble amino acids and glucose pass into the small veins of the villi and are carried first to the liver. Here the amino acids may undergo chemical changes or may pass unchanged into the general blood stream. Of the glucose, part passes through the liver into the general circulation, but any excess which the body does not require at the moment is stored in the liver as *glycogen* (pp. 236 and 237). From time to time the glycogen is changed again to glucose, which is delivered into the blood stream to satisfy the needs of the body's cells for carbohydrate food.

Fatty acids and glycerine pass first into the epithelial cells covering the villus.[2] Here they are recombined to form fat. The droplets of fat thus formed are then for the most part transported into

[2] Though the classical theory that all fat must first be split into its constituents before it can be absorbed is still held by many physiologists, certain observations within recent years have led others to believe that only part of the fat is digested in this way. According to the alternate view a large portion of the fat passes through the cells lining the intestinal wall in the form of microscopic particles of unaltered or partly altered fat. Minute canals in the intestinal cells have been described through which such particles could readily pass.

the lacteals. The fluid within these vessels is called *chyle*. The lacteals flow into larger lymphatic vessels, which empty in turn into the thoracic duct, which runs upward through the upper part of the abdomen and the thorax to empty its chyle into the left subclavian vein. So fat, or at least the greater part of it, reaches the general circulation by the lymphatic route and is laid down as adipose tissue in various parts of the body, especially beneath the skin. If the villi of a living animal are examined with a powerful lens and under a strong light, they can be seen to be continually swaying and twisting, shortening and lengthening, to stir up the fluids bathing their surfaces. By this means fresh materials are brought into contact with the covering layer of cells, and the rate of absorption is hastened as a result.

It has been pointed out (p. 178) that absorption from the intestine cannot be explained by simple physical laws; it is the result of physical processes and as such requires the expenditure of energy by the living cells of the intestinal wall.

chapter 23

THE MECHANICAL PROCESSES OF DIGESTION

The Teeth

Teeth are of different sizes and shapes, but in any tooth three parts may be distinguished (Fig. 23.1)—namely, the *crown,* visible above the gum; the *neck,* covered by the gum, but beyond the bone of the jaw; and the *root* or *roots,* held in the socket of the bone.

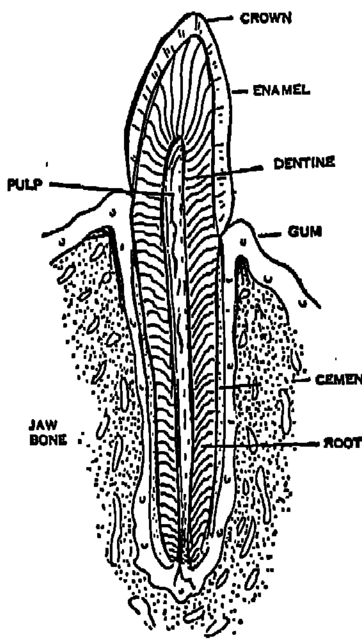


Fig. 23.1. Section through a tooth to show its structure.

If a tooth is sectioned, it is found to be composed of an outer layer of very hard white material—the *enamel.* This layer covers only the crown. Beneath the enamel is a less dense material resembling very hard bone and called the *dentine.* The center or core of the tooth is tunneled to hold delicate nerve filaments and blood vessels, which together are called the *pulp.* Between the dentine of the root and the bone of the jaw is a thin layer of modified bone called the *cementum.* Fine parallel tubules run outward from the pulp cavity through the dentine to end just beneath the enamel or the cementum. The teeth

develop within the bony substance of the jaws and, as they grow and enlarge, force their way into position.

Man receives two sets of teeth. The first set, called the *temporary* or *milk teeth,* does not appear as a rule until after birth. On rare occasions one or more teeth are already cut when a baby is born. It was formerly a common superstition that the child so born would grow up ill-natured. The first tooth to cut the gum is usually a lower incisor, which does so between the fifth and the eighth month.

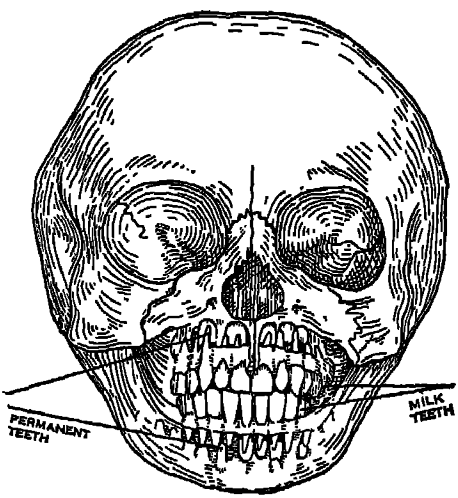


Fig. 23.2. Child's skull, showing the milk teeth and the unerupted permanent teeth above.

The *permanent teeth* are present within the jaw, though not fully formed, some years before the milk teeth fall out. X rays show them lying, all in a row, beyond the roots of the temporary teeth (Fig. 23.2). As the permanent teeth grow, they press upon the roots of the milk teeth and cause them to become smaller and smaller. That is the reason why a milk tooth comes out so easily at the proper time. The first permanent tooth, usually a molar, appears about the sixth or seventh year. The milk teeth number twenty, the permanent teeth thirty-two.

There are four kinds of permanent teeth—*incisors, canines, bicuspids,* and *molars* (Figs. 23.3 and 23.4). The first two types lie in the front of the jaws and are used for cutting and tearing the food. The bicuspids and molars, on either side of the mouth, serve to grind and crush the food into very fine fragments.

Decay of the teeth or dental caries.—The teeth always decay from without inward. Once the protective enamel is broken, the less resistant dentine falls an easy prey to the bacteria of decay. Microorganisms travel along the fine tubules of the dentine and, break-

ing down the comparatively soft material, form a cavity, which sooner or later involves the pulp with its very sensitive nerves. Toothache is the result. Chemically the teeth resemble bone, being composed largely of the minerals calcium (lime) and phosphorus. Calcium is very quickly attacked and dissolved by acids. Acidity of the mouth, for this reason, is looked upon as an important cause of tooth decay. Carbohydrate food (starches and sugars), lying in

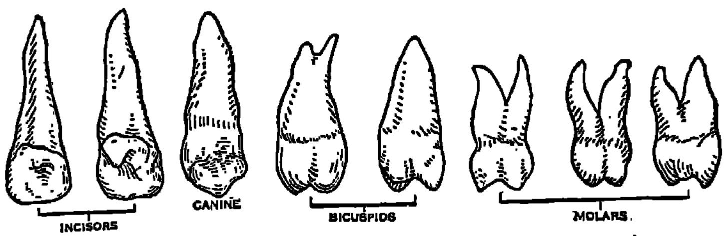


FIG. 23.3. The permanent teeth on one side of the upper jaw.

the crevices between the teeth and between the teeth and the gum, furnish food for germs, which through a fermentation-like action produce acid substances. The acid then attacks the enamel and later the dentine of the teeth. It is scarcely necessary, therefore, to

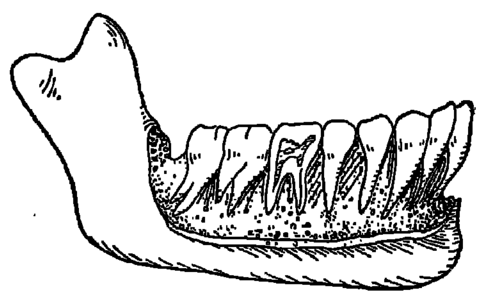


FIG. 23.4. The lower permanent teeth of one side. The bone has been removed to show the roots.

point out how important it is to brush the teeth thoroughly night and morning.

Though the dentist may tell us, we ourselves rarely know when the protective enamel has been broken and the underlying dentine exposed to the microorganisms of decay. Usually, it is only after decay has extended into the sensitive dentine or pulp that we are aware that the tooth is diseased. Conditions in the mouth probably

have been given an exaggerated importance as factors in tooth decay. Though brushing the teeth regularly is essential for hygienic reasons, it will not prevent dental caries. One person may have good teeth though he gives them little care in this regard, whereas another, though he cleans his teeth regularly, suffers from diseased teeth. It is likely that diet and general health play primary roles in the breakdown of tooth structure. An adequate supply of minerals —calcium, phosphorus and fluorine—and of vitamins—especially D and C—as well as not too great a proportion of carbohydrate food appears to be conducive to dental health.

Tooth decay is not a modern disease. Evidence of it may be found in Egyptian mummies, but it is only within comparatively recent years that the serious consequences which follow in the train of decayed teeth have been realized. Indigestion, blood poisoning, infections of the heart valves, arthritis, and kidney disease are some of the evils which may result.

Mastication.—In order that the tasks of the digestive glands may be accomplished with the least effort, the food must be thoroughly broken up into small fragments by the teeth. For instance, if we were to take a small lump of meat and drop it into a glass tube filled with pepsin and hydrochloric acid and leave it for an hour or two, we should find that only the surface of the meat had been digested into proteoses and peptones. On the other hand, if we should divide the same quantity of meat into fine pieces and repeat the experiment, it would be found that nearly the whole of the meat had undergone digestion by the pepsin. The incisors of the upper and lower jaws seize, tear, and cut the food. The molars grind and crush it. The jaws are brought together with tremendous force by powerful muscles attached to the skull bones above and to the jaw below. The force exerted by the human jaws was estimated three hundred years ago by an Italian physiologist and found to be equal to a pressure of several hundred pounds. The jaws also perform a side-to-side movement, by which the food is ground as well as crushed. As grist is passed into a mill, the muscles of the tongue, lips, and cheeks continually force the larger fragments of the food between the jaws for division into smaller and smaller pieces. All the while, saliva is pouring into the mouth to soak the food and turn it finally into a smooth pasty mass, which can be molded into a shape suitable for swallowing. Birds, of course,

possess no teeth. Defenseless creatures on the whole, they must snatch as much food as possible in a short time. This they store in their crops and fly from danger. Nevertheless, they possess that which mammals have not—a gizzard. This has strong muscular walls, which, by the aid of swallowed pebbles, grind and crush the food much as the food of higher animals is masticated by the teeth.

Swallowing

The first movement of swallowing brings the mass of food upon the upper surface of the tongue, which is then jerked sharply backward by means of muscles attached to its root. The food is thrown backwards and then pushed through the opening at the back of the mouth into the pharynx. Up to this point swallowing is a voluntary act. Once the food has entered the pharynx, however, it has started upon a journey over which we have no control. The subsequent stages of swallowing are purely reflex in nature (p. 282).

The pharynx is like a city square where two important lines of traffic cross (Fig. 23.5). Air passes from the nose down into the pharynx and through it to the larynx and lungs beyond. The pharynx also communicates in front and above with the mouth, and below with the esophagus. Other traffic must be held up to allow the food to pass from the mouth through the pharynx and down the esophagus. The opening from the nose into the pharynx is closed by raising that little fleshy partition or curtain (*soft palate*) which you may see hanging from the hard or bony palate if you open your mouth and look into a mirror. The opening between the mouth and the pharynx is called the *fauces*. The food is prevented from returning into the mouth, because the root of the tongue is raised, and the sides of this opening (the *pillars of the fauces*) are drawn together to block the way. The larynx is elevated to bring its opening under the shelter of the *epiglottis*—a small tag of mucosa-covered cartilage lying behind the tongue and above the larynx. For an instant the breath is held. So the food does not enter the larynx, except sometimes when, as is said, it "goes the wrong way." Having passed through the fauces, the food is seized and gripped by the muscular walls of the pharynx and forced down the only passage left open—the esophagus. The walls of this tube are muscular, and the stimulus of the food causes a worm-like

wave of contraction—the *peristaltic wave*—to run through the muscle. This wave sweeps the swallowed material downward and carries it into the stomach.

As the food approaches the lower end of the esophagus the muscle which guards the opening into the stomach (*cardia*) and is ordi-

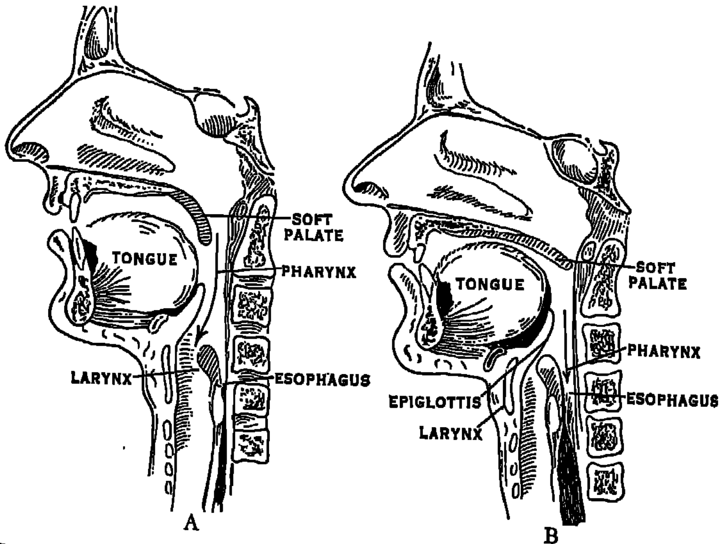


FIG. 23.5. Diagram of the mouth, pharynx, larynx, and esophagus to illustrate the act of swallowing. The positions of the tongue, palate, and larynx are shown in *A* during breathing, in *B* during swallowing.

narily contracted to prevent food from re-entering the esophagus from the stomach relaxes and allows the food to enter.

The Movements of the Stomach

Within an hour or two after a meal the lower half of the stomach becomes very active. It appears under X-ray observation to be continually changing its shape. This appearance is given by rings or waves of contraction (peristaltic waves), which start a little below the center of the stomach and run downward in quick succession. After digestion has advanced to the point where the food is of such a consistency as to be received by the duodenum, these waves sweep it through the outlet from the stomach (*pyloric opening*).

The upper half of the stomach remains quiet; no movements are seen. The stomach, so far as its movements are concerned, consists, therefore, of two distinct parts. The upper, larger region, which includes the fundus and lies in the upper part of the body (see p. 194) serves as a reservoir to hold the food for a time after it has been swallowed. The lower, pyloric part churns the food as it is mixed with gastric juice and passes it through the pyloric orifice into the intestine. As digestion proceeds, the food becomes thoroughly mixed and more uniform in consistency. The pyloric opening, which up to this time has been closed and has offered a barrier to the food carried to it by the peristaltic waves, now opens each time that a wave of contraction approaches, and the chyme is swept into the intestine.

It should be remembered that the movements of the stomach, and the physical changes which these movements bring about in the food, are of as great or perhaps of greater importance than the chemical transformations caused by pepsin and hydrochloric acid (p. 195). Persons in whom the gastric juice is entirely absent appear to suffer little or no difficulty in the digestion of food. The stomach may be removed, and, provided the consistency of the food is made suitable, little digestive inconvenience results. Disturbances of movements of the stomach, on the other hand—the too rapid entrance of, or the interference with the passage of, material into the duodenum—will induce ill effects. A prime function of the stomach is to prepare the food for intestinal digestion, to break it up, to add fluid to it, and, after reducing the entire mass to a semi-fluid consistency, to pass it on to the duodenum.

The Movements of the Intestines

The intestine is a long, coiled, muscular tube. The muscles of its walls are in two thin layers, one inside the other. The outer layer is composed of fibers which run lengthwise. The inner layer encircles the wall of the intestine. The entire intestinal canal of man is some 28 feet long. The first 23 feet is called the small intestine, since it is much narrower than the last 5 feet, which is known as the large intestine. (See Fig. 19.3.)

The small intestine (or bowel).—Though ordinarily we are unaware of the fact, the small intestine is in almost constant motion.

Contractions of the muscular walls are incessantly changing the diameter of the tube, moving the food from place to place, churning it up, and mixing it with the digestive juices. There are three types of movements in the small intestine: (1) segmenting, (2) pendular, and (3) peristaltic.

The *segmenting* movements are simple constricting contractions, which pinch the tube and its contents sharply several times a minute. Their purpose is to knead the food and thoroughly mix it with the intestinal juices. They do not move material along the tube. The *pendular* movements are also simple constricting bands of contraction; but they travel a few inches up and down the intestinal tube and churn the food back and forth. The *peristaltic wave* is a contraction which may travel long distances along the intestinal wall. It requires some special notice, since this type of contraction is found not only in the intestine but also in practically all muscular tubes of the body—esophagus, bile ducts, etc. We have already noticed it in the esophagus and in the stomach. A band of contraction is seen to seize the whole circumference of the tube with considerable force. The bowel may become blanched as a result of the compression of its blood vessels by the grip of the intestinal muscle. The contracting ring travels downward—rarely, if ever, upward. Progressing immediately in front of it is a circular band of completely relaxed muscle. It is apparent that, if the constricting band arises behind a mass of material and travels downward, the tube in the region over which it passes will be swept clean. The relaxed or dilated region which precedes the constriction must, of course, by removing any resistance to the passage of the material, aid its movement onward.

The colon or large intestine (or bowel).—The chief movement in this region is the peristaltic wave, which, aided by certain voluntary muscles of the abdomen and pelvis, empties the large intestine. The contents of the small bowel are much more fluid in consistency than the large, for in the former, large quantities of fluid are poured into the alimentary canal. On the other hand, absorption of similar quantities of water occurs in the large intestine, and the material in this situation is, in consequence, more nearly solid. The longer the material remains in the large intestine the drier it becomes. It is to be remembered that the fluids that are poured into the mouth, stomach, and small intestine are only lent for purposes of

digestion since the water is re-absorbed again from the large intestine into the blood.

The intestinal contents by the time that they have reached the lower part of the colon, which runs down the left side of the abdomen and into the pelvis, have become pasty in consistency. They are then called *feces*. This part of the intestine serves as a storehouse. *Evacuation of the bowel* or *defecation* is initiated by a strong peristaltic contraction of its muscular wall which forces the excrement into the lowermost section of the colon, which is called the *rectum*. Distension acts as a strong stimulus to the sensitive nerves in the rectal wall and the *defecation reflex* is set up. This reflex comprises a contraction of the rectal wall aided by a straining movement—contraction—chiefly of the abdominal muscles while the diaphragm is held in a position of nearly full inspiration. Normally, the rectum is empty except during and immediately preceding the act of defecation.

The Control of the Movements of the Stomach and Intestines

The movements of the alimentary tract from the pharynx to the large bowel are carried on automatically. They are beyond the control of our wills and, in perfect health, beneath our consciousness. Impulses are ceaselessly traveling from the stomach and intestine along afferent fibers to the spinal cord and brain. Impulses are discharged in turn along fibers of the autonomic nervous system to the musculature of the alimentary tract, which control its movements.

The *vagus nerve* carries excitor or motor impulses—i.e., impulses which increase the movements—to the stomach, small intestine, and upper half or so of the colon. These impulses arise in the medulla oblongata. Motor impulses to the lower half of the large intestine are conveyed from the lower part (*sacral region*) of the spinal cord by the *pelvic nerve*. Through it peristaltic waves are set up which empty the lower colon. The sympathetic nerves carry impulses which depress or inhibit the movements of the stomach and of the entire intestinal tract.

The intestine is excited to activity by the food within its cavity. Some foods are more stimulating than others to the sensory nerves

in the bowel wall. Solid particles in the food are particularly effective in exciting the peristaltic waves. Some foods, for instance, contain a large proportion of material which cannot be digested by the various ferments. This material is left as a residue, which, accumulating within the intestine, excites it to contraction. Green foods, large amounts of the non-digestible material cellulose, for this reason are valuable for maintaining regular movements of the digestive tract. Fruits such as grapes, raisins, and figs, since the seeds are not digested, act in the same way. Other fruits and vegetables contain certain chemical materials which are stimulating to the bowel. On the other hand, concentrated foods, such as cheese, eggs, meat, and bread, which are almost completely absorbed, have a depressing effect upon the bowel movements. Milk, since it contains a large proportion of lime, depresses the movements. Sluggishness of the intestinal tract, particularly of the large intestine, resulting in infrequent evacuations, is called *constipation*.

The type of food eaten and the habits of the individual are responsible in many instances for this condition. Though we have no direct control over the movement of the large bowel, it is remarkable how easily this part of the digestive tract can be trained. It can acquire good habits or bad. Not responding to nature's call makes the intestine insensitive and lazy. The longer the material is retained in the bowel the drier it becomes, and constipation is in this way encouraged. On the other hand, if the habit is formed of responding at once to the desire for relief, the large intestine plays its part and very soon regulates its movements so that they occur at a certain time each day.

We hear a great deal these days of ill health resulting supposedly from the accumulation of poisonous substances within the intestines. We are told to keep the digestive tract clean by irrigation, "internal flushings," etc., in order that these substances shall not be absorbed. This advice usually emanates either from ignorant but well-meaning persons obsessed by a theory of the way to health, or from patent-medicine manufacturers eager to promote the sale of their products. The lower intestinal tract is normally swarming with bacteria, and powerful poisons are always present. It is the cesspool of the body, and there is no use in denying the fact. It is designed to be a refuse pit and is quite capable of taking care of the poisons which are formed within it. Experimental work of recent years goes to show

that we need no longer be frightened by the bogy of intestinal intoxication. In the natural way, evacuation of the bowel once or twice a day is quite sufficient to keep the body healthy and fit. The discomfort, headache, and other unpleasant symptoms of constipation are well known. Yet even these are due, not to the absorption of poisons from the intestinal tract, but to quite a different cause—namely, the mechanical effect of the overloaded bowel upon the intestinal nerves and through these upon the nervous system.

part VI

Metabolism and Nutrition. Renal and Cutaneous Functions

chapter 24

METABOLISM

General Principles

Metabolism is a general term employed to embrace all the chemical processes carried on within the cells of the body (p. 28). Chief among these processes is the oxidation (combustion) of the food materials with the production of energy. The body resembles a furnace or a gasoline engine; but, whereas the furnace burns the carbon and hydrogen of coal or wood, and the engine the carbon and hydrogen of gasoline, the body obtains these elements from the food, and from their "burning" or oxidation derives mechanical energy and heat. Heat is a form of energy; and all other forms—mechanical, electrical, chemical, etc.—can be reduced to heat. By measuring the heat produced by a fuel when it is completely burned, therefore, the total amount of energy which the fuel contained can be ascertained. It is customary, therefore, to express the energy of a food simply in terms of heat.

The Calorie.—Fluid is measured by the quart or by some smaller or larger measure of the English system, or in cubic millimeters, cubic centimeters, or liters of the metric system; length is measured in inches, feet, etc., or in millimeters, centimeters, etc., and weight in such units as ounces, pounds, grams, or kilograms. So, too, we must have some unit for the measurement of a quantity of heat. The heat measure is called the *Calorie* (L. *calor* = heat). In physiological heat measurements a Calorie is the quantity of heat required to raise the temperature of 1 kilogram (about 2 pounds or a quart) of water 1 centigrade degree.[1]

[1] From 15° to 16°C. It is important that the terms *heat* and *temperature* should not be confused. The sense of touch tells us of any difference in temperature—whether an object is hot or cold, whether its temperature is high or low. Heat is a quantity,

When 1 gram (about 1/450 pound) of sugar or starch (carbohydrate) is burned outside the body, 4 Calories of heat are produced. One gram of fat, when burned in the same way, produces 9 Calories. When these substances are used for food and "burned" by the cells of the body, each produces the same quantity of heat as when an equivalent amount is burned outside the body. So we speak of one or other sample of food as having a certain *heat* or *caloric value*—a certain fuel value—meaning by this that it is capable of furnishing so much heat or energy to the body. On the other hand, only a proportion of protein food is burned within the body; a part (the nitrogen-containing portion) is incombustible. Protein can be com-

Food	Composition, in percent				Calories per pound
	Protein	Fat	Carbohydrate	Water and salts	
Beef (lean)	20	12	...	68	886
Pork	17	30	...	53	1,500
Eggs	13	11	...	76	755
Butter	1	85	...	14	3,500
Cheese	30	38	...	32	2,000
Milk	3	4	5	88	314
Sugar	....	....	100	..	1,790
Bread	9	2	53	36	1,200
Potatoes	2	....	18	80	350
Apples	0.4	0.5	11	88	200
Oranges	0.8	....	12	87	175
Lettuce	1	....	3	96	87
Tomatoes	7	....	4	95	100

and the sense of touch will not inform us of how much heat any substance contains, for the quantity of heat held by any material depends upon the mass of the material as well as upon its temperature. Thus a gallon of water may have a lower temperature than a single drop, but the *quantity* of heat held by the gallon may be immensely greater.

The physiological or large Calorie is a thousand times greater than the small calorie employed in physical heat measurements, which is the quantity of heat required to raise the temperature of 1 *gram* of water 1 centigrade degree. In order to distinguish it from the small calorie, the large Calorie is written with a capital C.

pletely burned outside the body; hence it must furnish more heat in the latter instance than when used as food. A gram of protein furnishes only 4 Calories of heat in the body as against 5 Calories outside. A list of some of the commoner foods with their composition and approximate number of Calories per pound is given on page 226.

The average man, during the course of the day, generates about 3,300 Calories. This quantity of heat is sufficient to raise nearly ten gallons of water to the boiling point. In order, then, to maintain this level of metabolism, the diet of the average healthy man should have an energy value of about 3,300 Calories. (See also p. 246.)

Heat production under different physiological conditions.—Several conditions influence the quantity of heat produced by the body. Obviously more energy is expended and more heat produced when work is done than during rest. The heat production may be increased 10 or even 20 times during strenuous muscular exercise. The temperature of the air is another important factor. In cold weather out of doors the body produces more heat than on a warm day in summer. The body tends to cool more quickly on a cold day—i.e., it loses more heat; therefore, in order to maintain the body temperature at the normal level, more fuel must be burned and more heat produced by the tissues. During sleep the metabolism is reduced below the waking level. The presence of food, especially protein, causes an increase in metabolism above that during fasting.

The Basal Metabolism and Its Measurement

There are two main methods of measuring the body's heat production—the *direct* and the *indirect*. In the *direct* method the subject occupies a chamber the size of a small room called a *calorimeter*. Through pipes in the walls and ceiling water at a known temperature is circulated, which absorbs the heat given off from the body. The chamber is perfectly insulated so that no heat can escape or enter. At the end of the experiment the quantity of water which has circulated through the pipes is calculated, and its temperature is ascertained by means of delicate thermometers. It is then a simple matter to calculate the number of Calories produced. For

example, if the quantity of water is 40 kilograms, and its temperature rise during one hour is 2 degrees Centigrade, then ($40 \times 2 =$) 80 Calories of heat have been produced in the subject's body. This method of *direct calorimetry,* as it is called, requires very expensive apparatus and is employed only in large institutions.

Indirect calorimetry requires no expensive equipment. It is based upon the following principles: The combustion of any food material involves the consumption of oxygen and the formation of carbon dioxide. Furthermore, when a given type of food is oxidized in the body, the quantity of oxygen used (and of carbon dioxide produced) is always the same for equal amounts of that particular foodstuff. These quantities are definitely known for the three different types of food. It is known, for example, that, when 1 gram of fat is burned, 2 liters (or about 1¾ quarts) of oxygen is consumed. We have already seen that this gram of fat produces at the same time 9 Calories of heat. Therefore if one knows the quantity of oxygen which the body uses in a given time, and the type of food (fat, carbohydrate, or protein) that the body is burning during that time, one may ascertain the quantity of foodstuff burned. The number of Calories which this amount of fuel produced (p. 226) can then be easily calculated. In other words, the consumption of a certain quantity of oxygen by the body when it burns a given foodstuff always corresponds to the production of a certain quantity of heat.[2]

[2] Since a given quantity of carbohydrate, fat, or protein, when it undergoes combustion uses a known volume of oxygen and produces a known volume of carbon dioxide, the type of food being oxidized by the body can be ascertained from the ratio of the volumes of these gases consumed and produced, respectively. This ratio is called the respiratory quotient or, briefly, the R.Q. Thus,

$$\frac{\text{Volume carbon dioxide produced (expired)}}{\text{Volume oxygen consumed (inspired and retained)}} = \text{R.Q.}$$

When 100 grams of carbohydrate are oxidized, 75 liters of oxygen are consumed and the same volume of carbon dioxide is produced. The respiratory quotient is, therefore, ($^{75}/_{75} =$) 1.00. When 100 grams of fat are oxidized, 142 liters of carbon dioxide are produced and 200 liters of oxygen used. The respiratory quotient is ($^{142}/_{200} =$) 0.71. The respiratory quotient of protein is 0.80. For mixtures of the three types of food the respiratory quotient will lie anywhere between the two extremes, depending upon the proportions of each in the mixture. On an ordinary mixed diet it is around 0.85. The heat equivalent of oxygen at different respiratory quotients is obtained from a table.

Except for very precise experimental work the respiratory quotient is not determined in measuring the metabolism of any individual subject. After several hours of fasting,

Since the value of the heat production in different persons must be capable of being compared, some standard set of conditions must be followed in making the measurements. Otherwise it would be impossible to tell whether a person's heat production were greater or less than it should be. During muscular effort, for example, or after a meal, a person would produce more heat than at rest or on an empty stomach. On this account, measurements of the heat production are made with the patient lying down [8] and several hours after a meal (without breakfast shortly after arising in the morning) and at a room temperature of about 20°C. The value of the heat production under these specified conditions is called the *basal metabolic rate* (B.M.R.).

OXYGEN CONSUMPTION UNDER STANDARD CONDITIONS (IN LITERS) AND THE HEAT PRODUCTION (IN CALORIES PER SQUARE METER OF BODY SURFACE) PER HOUR FOR VARIOUS AGE GROUPS

Ages	Male		Female	
	O_2	Calories	O_2	Calories
14-15	9.53	45.9	8.91	42.9
16-17	8.91	42.9	8.29	39.9
18-19	8.50	40.9	7.88	37.9
20-29	8.19	39.4	7.67	36.9
30-39	8.19	39.4	7.57	36.4
40-49	7.98	38.4	7.46	35.9
50-59	7.77	37.4	7.25	34.9
60-69	7.57	36.4	7.05	33.9
70-79	7.36	35.4	6.84	32.9

Note the gradual diminution in heat production with advancing years.

when the measurements are made, the body uses its fuel reserves and such a food mixture gives a respiratory quotient of 0.82. The heat equivalent of oxygen at this R.Q. is 4.825 Calories. This figure is therefore used in the calculations. That is, every liter of oxygen consumed at an assumed R.Q. of 0.82 corresponds to a heat production of 4.825 Calories.

[8] He should be lying quietly for at least 30 minutes before the measurement is taken.

Determination of the heat production from the oxygen consumption.—The oxygen consumption of any person can be ascertained by a variety of methods. The *Benedict-Roth apparatus* or some modification of it is most frequently used. The instrument consists mainly of a bell-type spirometer, two wide-bored tubes (inspiratory

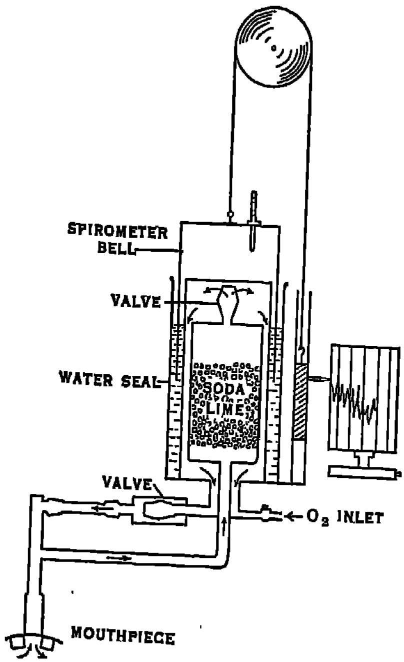


FIG. 24.1. Diagram of the Benedict-Roth apparatus used for the determination of the basal metabolic rate from the oxygen consumption.

and expiratory) and a mouthpiece (Fig. 24.1). The spirometer itself is a cylindrical vessel with two walls separated by a narrow space and an inverted single-walled vessel or "bell." The wall of this second vessel fits between the walls of the first and is counterpoised by means of a weight and pulley as shown in the figure. Water fills the annular space between the walls of the first vessel and acts as a seal. Before the observation is started, oxygen is run into the bell until the pointer is raised to the zero mark on the graduated scale covering the rotating drum.

A clip closes the patient's nostrils while he breathes quietly into the apparatus through the mouthpiece and tubing. The carbon

dioxide is absorbed from his expired air by soda lime. The heat production is arrived at from the oxygen consumption alone. The bell falls as the volume of oxygen is reduced; the quantity consumed by the patient is calculated from the descending curve drawn by the writing point on the graduated scale.

Heat production and surface area.—The heat loss of the body, as of any other hot object, is related to its surface area—the greater the surface, the greater the heat loss. The greater the heat loss from the animal body, the greater, automatically, becomes the heat production. In brief, then, the body of a person with a large surface area produces more heat than one with a smaller area. Since the surface areas of different persons vary considerably, it is not customary to express the metabolic rate as so many calories per person per hour, or even as so many calories per pound of person per hour. Instead, a square meter of body surface is used as the standard unit for comparison. The surface area of a person is calculated from his height and weight. The normal metabolic rate of an adult man is about 40 calories per square meter per hour. In young persons it is greater than this, and in older persons it is less. The rate is also less in females than in males of the same age. (See table, p. 229.)

Variations in the basal metabolic rate from the normal.—If the basal metabolic rate is the same as that in a large number of people of the same race, age, and sex, the figure is said to be normal. If, however, the rate is less than that of the average for normal people, the rate is said to be lowered. Overactivity of the thyroid gland (hyperthyroidism, page 406) causes a great increase in the basal metabolic rate, whereas decrease in the activity of the thyroid gland (hypothyroidism) results in a lower rate. It is raised in fever. The basal metabolic rate has been determined in practically all diseased conditions, and the determination of this value is of great assistance to the physician in making a diagnosis or in following the progress of his patient.

chapter 25

THE REGULATION OF THE BODY TEMPERATURE

The temperature of the human body is about 98.6°F. It varies slightly above or below this level in different persons but remains practically unchanged from day to day or week to week in the same person, whether he is exposed to a low or to a high air temperature.

The reader must have been struck by the sight of an animal such as a horse, with a thin coat of fur, standing apparently quite comfortably on the street in zero weather. A pail of water would very soon freeze to a solid block of ice at this temperature. The temperature of a cold-blooded animal such as a frog or a snake would also fall to near that of its surroundings. But if we were to take the horse's temperature, we would find that it was just the same as on a blistering hot day of 90 degrees in the shade. How does the horse or a man keep the body temperature unchanged though the day be hot or cold? In order to answer this question, we must first recall the fact that practically every cell in the body is constantly oxidizing food materials and generating heat, the amount of which can, when necessary, be increased or diminished. Upon a cold day in winter one stokes up the furnace; one shovels in more coal and turns on the draughts. The body is heated up in a similar way; its fires are fed with more food fuel, and more must be eaten. Everyone knows how hungry he becomes on a brisk, cold day. The body also fans its fires by taking in more oxygen through the lungs. So, through an increased heat production the body is kept warm against the coldness of the air surrounding it.

In the summertime we let the furnaces of our houses go out. The fires of the body cannot go out so long as life lasts, but less fuel

can be used. The metabolic rate is, therefore, less at high than at low temperatures. So, by altering the quantity of heat produced within our bodies, we are able to keep the body temperature at a constant level so long as the heat-regulating mechanisms are acting efficiently.

Fish, frogs, turtles, snakes, and other cold-blooded animals cannot regulate their temperature; like that of any inanimate object

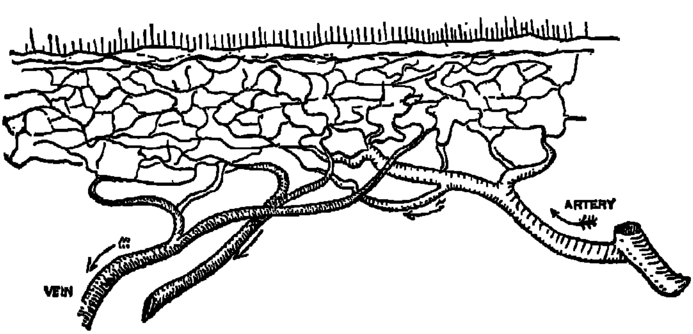


FIG. 25.1. Diagram to illustrate how the blood is carried through the vessels of the skin, which constitute the body's heat-radiating system.

the temperature of their bodies rises or falls with the temperature of the environment.

There are other means which the body calls to its aid for the regulation of its temperature. In the first place, the blood carries the heat from deeper parts of the body and spreads it out just beneath the surface of the skin. Here it can be cooled by the air if the body should get too warm. How warm one becomes if he runs or skates or plays football even on a cool day, and how flushed the skin appears and how hot it feels! The exercise has fanned the body's "fires"; the blood, therefore, is rushed to the fine blood tubes (capillaries) of the skin, and the extra heat is radiated into the air. The heat is lost, and the blood is cooled in very much the same way as the water coming from the engine of an automobile is cooled by being passed through the radiator. The capillaries of the skin constitute the body's radiator (Fig. 25.1). When the day is very cold, the blood is confined to deeper regions of the body; less is allowed to flow through the capillaries of the skin. A person's face then is paler and may look pinched and cold. Should the body

become very warm, either because the day is hot or because strenuous work is being done, it cannot be cooled sufficiently by radiation; the skin is then moistened with sweat. The many sweat glands of the skin pour their secretion, which is a weak aqueous solution of sodium chloride and other salts together with urea, upon the surface of the body. The sweat evaporates quickly, as a rule, and in doing so cools the skin and cools the blood flowing through the capillaries lying beneath the surface.

Any liquid, when it evaporates, uses up heat and cools the surface upon which it lies. More than half a Calorie (p. 223) is required for the evaporation of 1 cubic centimeter (25 drops) of water. When one stands in the air with the body wet after a swim, the skin often feels much cooler than when one is in the water. This is because the air quickly evaporates the water from the skin. We feel very hot when we perspire, but we should feel much hotter if we did not. Perspiring does not make us hot; it is the heat which makes us perspire. A strong, healthy man can live and actually do work in a temperature (250°F.) that would fry an egg; yet his temperature does not rise, because he is able to perspire. Should his sweat glands fail, he would quickly die of heat stroke.[1]

Large quantities of water are also evaporated from the body in the expired air; this, therefore, is another means whereby the body may get rid of excess heat, and is of very great importance in some animals, such as the dog, which possesses no sweat glands except a few upon the pads of the paws. An increase in heat production above a certain level in these animals is countered by rapid breathing—panting.

The heat of the body is the result of chemical reactions—chiefly the oxidation of food materials in the muscles and liver. An important reaction to cold is increased tension of the skeletal muscles, and contraction of smooth muscle fibers in the skin; the latter action gives rise to the roughness of the skin popularly known as *goose flesh*. If the cold is severe and the body not adequately protected by warm clothing, fine intermittent contractions of the skeletal muscles occur, generally known as *shivering*. Heat production is thus increased. In very strenuous muscular exercise the greatly

[1] This temperature can be withstood only provided the air is dry. Humid air at this temperature would cause death, since evaporation of the sweat could not occur freely.

increased heat production may cause the temperature of a healthy person to rise temporarily to 103°F. or more; the reason for this is that heat cannot be dissipated from the body as quickly as it is generated by the contracting muscles.

Body temperature is under the control of the central nervous system, mainly in that part lying at the base of the brain and known as the *hypothalamus* (p. 423). An animal whose brain has been cut across between this region and the medulla oblongata cannot maintain normal body temperature. Like that of a cold-blooded animal, its temperature approaches the temperature of the environment.

The temperature-regulating mechanisms are at their greatest efficiency in strong, healthy adults; in infants and elderly persons they are imperfect.

In illness the body may be unable to regulate its temperature efficiently. The cells, as a result of poisons formed by microorganisms or derived from other sources, may produce an unusually large quantity of heat. Radiation of heat from the surface of the body may also be imperfect. The balance of heat loss and heat production is upset. The result is that the temperature rises, and a person is then said to have a *fever*. The temperature may rise to 106° or 107°F. without causing permanent damage to the body's tissues, but heating the tissues beyond this temperature is usually of itself definitely injurious, and recovery rarely occurs.

Fever may follow any great reduction of the total water of the body. The tissues then hold less fluid and the volume of circulating blood may be reduced, as is also evaporation from the skin. Heat loss is thus diminished. Certain drugs, such as aspirin, reduce the temperature in fever probably by drawing water from the tissues into the blood stream. Through the increase in circulating fluid produced in this way more heat is radiated from the surface of the body.

chapter 26

THE METABOLISM OF CARBOHYDRATE, FAT, AND PROTEIN FOODS

Carbohydrate Metabolism

Carbohydrates (mainly glycogen and glucose) are found in all parts of the body, but they are stored principally in the liver and muscles. The liver may contain from 5 to 20 percent sugar under normal conditions, while the muscles usually possess about ½ to 1 percent. The much larger total amount of muscle tissue, however, enables it to hold at least as much sugar as the liver. The blood contains approximately 0.1 percent sugar, but this amount varies considerably in health as well as in disease. The blood sugar tends to be increased by sugar absorbed from the intestine, and by sugar formed from other materials in the liver. The blood sugar tends to be decreased by muscular exercise, since increased amounts are then burned. *Insulin* decreases the blood sugar by promoting the formation of glycogen (p. 209), and by increasing the combustion of sugar. *Adrenalin*, on the other hand, raises the blood sugar by calling out the carbohydrate reserves from the liver and the muscles.

When starches, other carbohydrates, or ordinary granulated sugar (sucrose) are taken into the stomach, they rapidly pass into the duodenum, where the ferments of the pancreas and intestine reduce the complex sugars to a simpler form, which is readily absorbed into the blood stream (p. 203). A rise in blood sugar occurs within a few minutes after the ingestion of carbohydrate. The sugar (glucose) which is absorbed into the blood is carried to the liver, muscles, and other tissues for storage as glycogen, or for direct combustion to provide energy.

Insulin—the carbohydrate hormone.—Insulin is one of the hormones; it is secreted into the blood from certain cells in the pancreas (p. 201) which are arranged in isolated groups and called *the islands of Langerhans.* A great many attempts to obtain insulin from the pancreas were made as a result of the observation in 1889 of Mehring and Minkowski, who showed that complete removal of the pancreas from animals resulted in the production of a severe derangement of the utilization of sugars in the body identical in nature with diabetes in man. Conclusive proof of the existence of insulin was not secured, however, until 1921, when Banting and Best, working in the laboratory of Professor J. J. R. Macleod in Toronto, obtained an active preparation.

Experiments based upon hypotheses formulated by Banting showed that, after the elimination of the cells of the pancreas which produce the enzymes (trypsin, lipase, and amylase), the secretion of the cells of the islands of Langerhans (i.e., insulin) could be extracted (Fig. 22.2). The extracts containing insulin showed very definite effects upon the carbohydrate metabolism of diabetic animals and man. The crude extracts were purified with the help of Dr. J. B. Collip, and insulin is now used in all countries of the world in the treatment of the disease known as *diabetes mellitus.*

Insulin, in addition to facilitating combustion of carbohydrate, promotes the storage of sugar as glycogen in the muscles, regulates the rate of sugar production by the liver. When an overdose of insulin is given to animals or to man, certain signs of nervous hyperexcitability and in-co-ordination of muscles and other signs of more serious portent may be produced. These symptoms are due to the greatly reduced concentration of glucose in the blood; they may be dissipated very quickly by the administration of sugar.

Diabetes. Diabetes mellitus is a condition in which the metabolism of sugars has become disturbed, due to a deficiency or absence of insulin. The untreated diabetic patient suffers from extreme thirst, hunger, and loss of weight and strength. Sugar is formed in large quantities in the liver; it accumulates in the blood, and part of it is excreted in the urine. Fat metabolism also becomes upset, and certain products of the breakdown of fat accumulate in the blood and produce serious conditions which may end in coma and death. All signs and symptoms of diabetes are eliminated by the administration of appropriate amounts of insulin. It has been calculated

that over a million people depend upon the daily subcutaneous administration of this hormone. Depancreatized animals can be kept alive indefinitely when appropriate amounts of insulin are provided. Insulin is not active when given by mouth, as it is rapidly destroyed by the intestinal enzymes.

Insulin is made from beef or hog pancreas, by extraction of the fresh material with acid alcohol. The active material can be purified and crystallized; 25,000 units are contained in one gram of insulin crystals.

The mortality rate of diabetics has decreased markedly. This decrease is particularly notable in the early age groups, in which diabetes was previously a rapidly fatal disease. It is perhaps not generally appreciated, however, that insulin has provided an extremely valuable tool for the investigation of numerous physiological problems of great importance.

Fat Metabolism

Several references to the interesting mechanisms by which the fatty materials of our food—butter, cream, vegetable oils, meat fat, etc.—are digested and rendered available for the provision of energy in our bodies have already been made (p. 171). It is unnecessary to discuss again in detail the digestive processes by which the fats are broken down in the small intestine to their components or building stones, the fatty acids and glycerine (p. 203). It appears that the intact fats cannot pass through the wall of the intestine, which is easily traversed by the products of digestion. No sooner have these products passed through the intestinal wall, however, than they reunite to form fat. Part of the fat reaches the blood stream indirectly; the droplets are absorbed into the fine lymph vessels (lacteals) of the intestinal wall and are conveyed by the lymphatic duct to the subclavian vein (p. 209). The remainder of the fat is absorbed into blood vessels of the intestine and is carried to the liver.

The storage of fat.—Although every tissue in the body is composed in part of fatty materials, the chief storehouses are the tissue spaces just beneath the skin, the areas about the kidneys, and the cells of the liver. In fat the body possesses the most compact store of energy, since over twice as much heat is produced when an ounce

of it is burned as when sugar or protein undergoes combustion in the "fires" of our bodies. It is very interesting, also, that fat is the only one of the three major classes of food material which is stored free of water. Carbohydrate and protein are stored in combination with water, which forms more than half the total weight of these stored materials. This means that at least four times as much energy is stored in an ounce of fat as in the same weight of stored carbohydrate or protein. It is not only the fat of the diet which forms fat in the body. Carbohydrate food and part of protein, if taken in greater amounts than the body requires for energy purposes, is converted to body fat and stored. Farm animals are fattened by feeding with wheat, oats, and other carbohydrate materials.

Disturbances of fat metabolism.—In certain abnormal states of the endocrine organs, e.g., defective function of the thyroid or pituitary, or of the hypothalamus, the deposition of fat may be very extreme (pp. 403, 411, and 423). On the other hand, overactivity of the thyroid gland (p. 406) causes depletion of the fat stores. Persons with such overactive glands are usually underweight.

In diabetes mellitus the rate of breakdown of fats becomes very rapid, and poisonous products, such as acetone, which under normal conditions are quickly destroyed, may accumulate in the body. These poisons may produce the dangerous coma or stupor in which many diabetics used to die before insulin became available. Insulin helps to regulate fat as well as carbohydrate metabolism.

Obesity. An overweight condition due to an excess of fatty tissue is called *obesity*. Though obesity is abnormal in the sense that the body weight is well above the average of other persons of the same height, the physiological processes concerned in its production are, in the great majority of cases, normal. Though, as mentioned above, excessive fat formation is sometimes due to disease of the glands of internal secretion, most authorities are agreed that the ordinary overweight person simply eats too much for the exercise he takes. It is a matter of the balance between the intake (food) and the output (work) of energy. Food which cannot be used as fuel for the performance of work is stored largely as fat. For example, the lumberman or other worker out of doors in winter eats food with an energy value of 5,000 Calories or more, yet does not grow fat, as a man who led a sedentary life certainly would were his diet as liberal.

Yet obesity, if not strictly a disease in itself, certainly seems to be in many cases a forerunner of serious disease. Statistics show that arterial hypertension, heart disease, and diabetes are more common in overweight persons than in those who are normal in weight or under the average. The length of life of obese persons as a group is shorter than that of lean persons.

Protein Metabolism

The general chemical structure of protein has been given on page 172. It was said there that the protein molecule was built up from a number of smaller molecules, the amino acids, of which there are several different kinds. For this reason the amino acids are often referred to as the "building stones" of protein. During digestion the "protein building" is placed in the hands of the wreckers—the enzymes of the alimentary tract. The building stones are torn apart and, after passing through the intestinal mucosa are conveyed by the blood to various parts of the body, where they are synthesized again in the building of new structures or used in repairing dilapidations sustained by the protein fabrics composing muscle, brain, liver, kidney, etc.

Protein in the repair and building of tissue.—We have seen that fats and carbohydrates are "burned" by the tissues and provide heat to keep our bodies warm and supply energy for the accomplishment of work. But neither of these food materials can take the place of protein. Protoplasm, which is chiefly protein, can be built only from protein. Though, as we shall see presently, this food can be partly oxidized and so can serve to replace some fat and carbohydrate and furnish energy, protein is of chief importance in (1) building new tissue, as in the growing body, and (2) repairing old tissue which has lost some of its protein substance.

The protein structure of the body to a small extent is constantly breaking down, crumbling like an old building, or wearing out like a piece of machinery. The broken parts are cast from the body in the urine as urea, amino acids, and other nitrogenous substances. It is this inevitable loss which is made good by the amino acids derived from protein food. Any amino acids derived from food protein which are left over after the repairs have been completed, or in the growing animal are not required for the formation of new

tissue, are also broken up and changed to a large extent into urea, which is then excreted. Urea, then, has two sources: broken-down tissue protein, and protein of the food. If a contractor orders more stones or bricks than are required for a work which he has undertaken, there need be no waste, for he can use what remains in some other building, or return them and have their cost refunded. Since those amino acids absorbed from the intestine and not used for growth or repair are broken up, it is clear that the body must be a very wasteful builder. Yet not all the fragments of the protein molecule are discarded as urea. Some are of service in another way, and this brings us to a third use which may be made of protein—namely, to provide energy.

The use of protein as fuel.—Each amino acid is made up of two parts. One of these is composed, like fat and carbohydrate, entirely of carbon, hydrogen, and oxygen, and hence can be oxidized by the tissues. The other part contains nitrogen, which cannot be burned. With respect to its composition an amino acid resembles not so much a stone as an object made partly of inflammable material, such as wood, and partly of an unconsumable part, stone or iron. Should the whole amino acid be required for building or repair purposes, it may be used in its entirety; but if it is not required for either of these purposes, it is separated into its two parts; the wooden (carbon) part is burned completely, just as though it were fat or carbohydrate, but the non-inflammable stony or iron-like part (nitrogen) remains unconsumed. It is this portion which is excreted in the urine as urea. Urea in this way resembles the ashes of a wood fire, or a nail, a stone, or other material which has been left unharmed by the fire.

Under ordinary circumstances we depend to only a small extent upon protein food to supply our bodies with energy. This, as mentioned elsewhere, is furnished chiefly by the carbohydrates and fats of the diet. Nor could one live upon protein alone, because, since the part which can be burned is only a part of the whole, one cannot eat enough protein to supply the necessary energy. A carnivorous animal, such as a dog or a cat, on the other hand, can consume large quantities of meat, which a man could not attempt, and so is able to derive from this the necessary quantity of oxidizable material to heat its body and accomplish work.

The breakdown of body protein.—If a man is not supplied with a sufficient quantity of food to furnish his body with the necessary energy, he uses the stores of carbohydrate (glycogen) and fat within his body and loses weight. If he eats more non-protein food than the body requires, carbohydrate and fat are stored. If he eats more protein than is necessary to replace the wear of his tissues, a great part of it (nitrogen) as mentioned above, is wasted. The remainder is burned or may in part be stored as fat. From 70 to 80 grams of protein is considered to be sufficient to meet the daily requirements of the adult human body. Of this about 50 grams should be of first-class nutritional value, such as is furnished by eggs, milk, liver, kidney, and good cuts of meat. Children require somewhat more protein per pound of body weight in order to permit normal growth. Also, a greater proportion should be of first-class quality.

When no food at all is taken for a long period, any stores of carbohydrate and fat which the body may contain are first used up, but when they run short and there is no longer a sufficient amount of energy available from these sources, the protein of the tissues is used. With a minimum expenditure of energy the body can carry on for perhaps eight or nine weeks in this way but not for much longer. After this time the functions of the body cannot continue; the body's heat cannot be maintained, and death results.

These facts may be made clearer by an illustration taken from everyday life. In winter, in order to heat our houses, we stoke the furnace or stove with fuel from our coalbins or from the woodpile. The coal or wood fuel may be taken to represent the carbohydrates and fats which we take three times a day in our meals. If, however, the coalbin were to become empty and there were no means of refilling it, we would, rather than allow the furnace to go out, burn the furniture and any odd inflammable material which could be found. This material represents the stores of fat and carbohydrate within our bodies which are burned during the first days of fasting. Later, when no stick of furniture remained, we would be forced to demolish the interior of the house itself, ripping up the flooring and tearing down the doors and wainscotting and other inflammable parts of its structure to keep the fire burning. The rubbish which could not be burned would be thrown outside. So it is with the body; in the last resort its structure is used for fuel. The carbon of its protein in muscle and other tissues is consumed to furnish energy.

chapter 27

NUTRITION

The body derives its energy solely from food (chiefly fat and carbohydrate). It receives the materials necessary for growth and repair largely from protein. Lean meat, which is about 25 percent protein and the remainder water and salts, does not possess sufficient energy value as the sole food for man. The particular value of meat is that it furnishes protein for growth, for the repair of body tissue, or for the manufacture of essential secretions (p. 240).

We have seen already how the digestive processes prepare the foodstuffs for absorption into the blood and for their utilization by the tissue cells. But materials other than these three food principles are necessary in order that the efficiency of certain vital functions shall be maintained. A certain quantity of water must be taken into the body daily, since moisture is lost in the breath and urine and from the surface of the body. Certain substances in small amounts—salts and vitamins—are also absolutely essential.

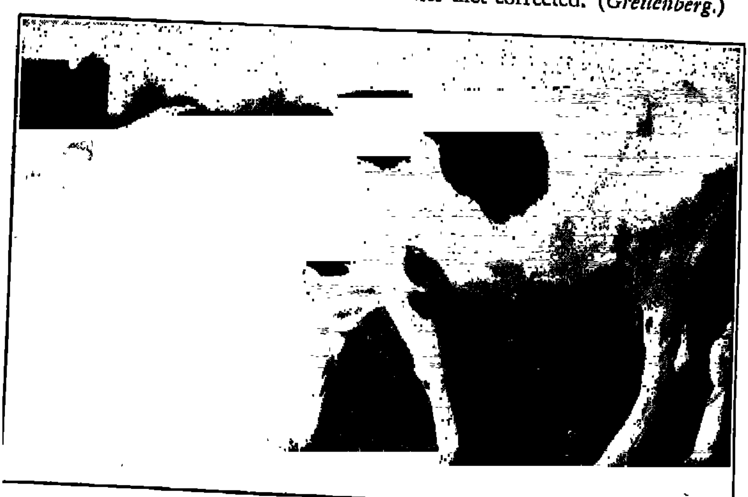
The processes whereby the body makes use of these various substances and achieves that state which we all recognize as normal and healthy are embraced in the word *nutrition*. The production of energy and the processes of tissue growth and repair have been spoken of in the preceding chapter. Other phases of nutrition may now be considered.

The Need for Inorganic Salts and Water

Inorganic salts.—Numerous inorganic salts are found in small amounts in our diets. Calcium and phosphorus are necessary in quite large amounts to provide calcium phosphate—the important salt of which the bones are mainly formed. Iron is necessary for

Upper, mice on diet containing poor quality protein; *lower,* mice of same age receiving high quality protein. (*After Mendel.*)

Left, improper diet; *right,* same child after diet corrected. (*Greuenberg.*)



Cow eating bone to obtain phosphorus absent from pasture. (*R. A. McIntosh.*)

FIG. 27.1. To show effects of improper diet.

the formation of hemoglobin and the pigment of muscle, and for certain enzymes essential for tissue respiration. Iodine is an essential component of the active substance made by the thyroid gland—thyroxin (p. 406). Calcium and phosphorus are found in milk and meat. Iron is obtained from vegetables such as spinach, from fruits, and from meat. Iodine is present in abundant amounts in the foods grown on certain soils, but in other regions the soil is deficient in this element and cannot supply it to the plant life. The significance of iodine is also discussed under the thyroid gland (p. 404). Common salt (sodium chloride) and other soluble salts must be supplied to the blood and tissue fluids in order that a suitable environment may be maintained for the cells bathed by these fluids. Zinc, copper, and certain other elements are required in minute amounts.

Water.—From 75 to 80 percent of the soft tissues of animals is water. Water is lost from the body in the breath, in the perspiration, and through the kidneys. The water content of the body must be maintained at a constant level, since excessive loss of water may cause great damage. We obtain water in our food and drink, and in addition water is formed in our bodies by the oxidation of the hydrogen of the food. This is called the water of metabolism.[1]

The value of different proteins.—Proteins differ widely in their assortment of amino acids, and the different amino acids are not all of the same nutritional value. Some amino acids are absolutely essential to life; others are essential for growth. Proteins which lack the latter amino acids are unsuitable as the sole source of protein for young persons; those lacking in the former types cannot be used as the sole source of protein for either children or adults. The most valuable proteins are found in meat, eggs, milk, and wheat.

Planning a Balanced Diet

In planning a diet the following must be taken into account:

1. The total energy requirement—i.e., the heat or caloric value of the food.

2. The proportions of the three main foodstuffs—carbohydrates, fats, and proteins.

[1] One hundred grams of fat when oxidized in the tissues yields more than 100 grams of water. The same amount of perfectly dry carbohydrate produces in the same time about 55 grams of water. Protein produces some 40 grams of water per 100 grams.

3. Essential minerals.
4. Vitamins.

The diet of a healthy adult must have an energy value which will just balance the energy which his body expends. If his food yields more Calories than he expends in work, in maintaining his body temperature, and in other vital functions, the excess will be stored as fat and he will gain weight. If he consumes food which provides less energy than is required he will lose weight. The total energy requirement varies, of course, with the size and occupation of the individual, with the climate and season, and with the age and sex. A man doing heavy outdoor work, for example, may require a daily diet of 4,000 or 5,000 Calories, or even more, whereas 2,500 Calories or less would be ample for an office worker.

In order, then, to arrive at the Calorie requirement of any individual the number of Calories required for work must be determined and (allowances having been made for climate or any other modifying condition) added to the value for his basal metabolism (p. 229). Now the metabolism during sleep is less than the basal metabolism by at least 10 percent. The basal heat production during waking hours (16 hours) and the metabolism during sleep (8 hours) must for this reason be calculated separately for the 24 hours.

The Calorie value of the diet of a man of average size who expends a total of about 3,300 Calories daily is, therefore, made up from the following items:

	Calories
1. Basal metabolism (70 Calories per hour during the waking state of 16 hours)	$70 \times 16 = 1{,}120$
2. Metabolism during sleep (63 Calories for 8 hours)	504
3. Allowance for work	1,500
	3,124
4. Specific dynamic action of food[2] (6 percent of 3,124)	187
	3,311

From 45 to 50 percent of the total Calories of the diet should be furnished by carbohydrates, 35 to 40 percent, or even more, by fat,

[2] This item is an allowance for the increased metabolism caused by the food itself. This effect of the food is called its specific dynamic action. Food, especially protein, has a stimulating action on heat production quite apart and in excess of its Calorie value. The phenomenon has never been given an entirely satisfactory explanation.

and from 12 to 15 percent by protein. These proportions of the three foods vary considerably under different conditions—e.g., age, sex, climate, and occupation. A much higher allowance of fat, for example, is required in northern climates than in tropical or subtropical zones. A larger proportion of protein is also an advantage in cold weather. The diet of laborers, growing children, and persons who have lost weight as a result of illness or from other cause should contain a more liberal amount of protein than is required for healthy adults doing light work. The daily allowance of protein for the average adult is usually placed at 70 to 80 grams (p. 242).

Apart from their value in furnishing energy, fats contain essential fatty acids (*linoleic, linolenic,* and *arachidonic*) which are absolutely essential in nutrition; severe nutritional defects result when they are absent from the diet.

The importance of various minerals in the diet has been mentioned (p. 243). The vitamin requirements will be discussed in the next section.

The Vitamins

The essential importance for nutrition of minute quantities of certain substances in food has been generally recognized only within comparatively recent years. When these indispensable materials were first discovered little was known of their chemical nature, but since they were thought, in error, to belong to a class of nitrogenous substances known as amines, they were called *vitamines* (L. *vita* = life). This name has been retained but the spelling has been modified to *vitamins.* As new kinds were discovered and added to the list, each was designated by a letter—A, B, C, etc.

Vitamins have become very popular, and many commercial concerns try to increase their sales by advertising that their particular product contains this or that vitamin. This is too often simply "sales talk." Even in the case of vitamin preparations offered for sale in tablet form, the only assurance that the public has that a particular tablet contains the vitamins as stated is the reputation of the manufacturer.

The following is a list of the better known vitamins:

Vitamin A (antixerophthalmic).

Vitamin B complex—Thiamin (antineuritic), riboflavin, nicotinic acid, etc.

Vitamin C (antiscorbutic).
Vitamin D (antirachitic).
Vitamin E (antisterility).
Vitamin K (antihemorrhagic).

Vitamin A.—Vitamin A is present in largest amounts in cod-liver oil and in the liver oils of various fresh-water fish—e.g., halibut.

FIG. 27.2. A rat with abnormalities of the eyes and conjunctivae as a result of vitamin A deficiency. (*From "Therapeutic Notes." Parke, Davis and Co.*)

The livers of mammals are also rich in this vitamin. The reason that the liver is such a rich source of vitamin A is that the vitamin is produced in this organ from *carotene* absorbed from the intestine. Carotene is a yellow pigment found in many green and yellow plants used as food by both man and animals. Carotene, since it is converted in the body to vitamin A, is called *provitamin A*. We can, therefore, obtain a supply of vitamin A either from the carotene of such vegetables as carrots, yellow corn, lettuce and many fruits, or already formed from animal products, such as fish oils and dairy products—cream, milk, butter, and eggs. The vitamin A content of dairy products depends upon the amount of carotene in the cow's food (Fig. 27.2).

A well-balanced and liberal diet usually contains sufficient amounts

of carotene or of vitamin A for normal nutrition. But when dairy products, vegetables, and fruits are absent from the diet or are present in meager amounts, serious nutritional defects result. The chief effects of vitamin A deficiency are seen in the skin, eyes, and nervous system. The disorders of the skin take the form of dryness, roughness, and a pimply rash. The membrane covering the surface of the eyes and lining the lids (*conjunctivae*) becomes dry owing

FIG. 27.3. *Upper photograph*, pigeon suffering from polyneuritis, the equivalent of beriberi in man. *Lower*, the same bird an hour after treatment with vitamin B_1. (*After Funk, redrawn.*)

to the suppression of the flow of tears which ordinarily lubricates them. Since vitamin A is required for the light-sensitive visual purple of the retina (p. 329), night blindness may result if this vitamin is lacking from the diet. Various degenerative changes in the nerves and nerve tracts of the central nervous system are produced by very severe deficiency of vitamin A.

The vitamin B complex.—Certain nutritional defects observed in experimental animals fed deficient diets were attributed by earlier investigators to the lack of a single dietary essential. It has since been shown that the defects were not due to the absence of one substance and that vitamin B, so called, consisted of a group of closely associated vitamins. These are now referred to as the B complex. They are sometimes designated by numbers placed after

the letter B—B_1, B_2, etc., but more usually they are distinguished by special names (Fig. 27.3).

The chief, or at least the best known, members of the B complex are *thiamin* (or the *antineuritic* vitamin), *riboflavin, nicotinic acid* (or *niacin*) and *folic acid.*[3]

Thiamin, the antineuritic vitamin, or B_1, is essential for the normal nutrition and functioning of the nervous system. In its absence the metabolism of carbohydrates does not proceed normally. When the diet is lacking in the antineuritic vitamin a condition of the nerves develops leading to paralysis of the limbs. There also may be edema and dilatation of the heart. This deficiency disease, known as *beriberi,* is seen most commonly in Eastern countries—China, Japan, India, the Malay States, etc.—where the natives subsist mainly upon polished rice, that is, rice from which the outer coverings of the kernel have been removed in the milling process. Beriberi is cured by feeding whole rice or the outer coverings of the rice grain (rice polishings), or any other good source of the vitamin. Pure thiamin, which is now made synthetically, is today more usually employed.

The richest sources of this vitamin are whole-grain cereals, milk, liver, and kidney.

Riboflavin belongs to a class of yellow fluorescent pigments known as *flavins.* It is found in largest amounts in milk, liver, kidney, and lean meats, especially lean pork. Severe abnormalities of the eyes result when it is absent or when it is present in very small amounts in the diet. The chief eye defect is a growth of fine vessels into the cornea, which normally is bloodless and perfectly transparent. The eyes also become highly sensitive to light, being unable to tolerate light of even ordinary intensity. Another effect of riboflavin deficiency is the appearance of deep creases or fissures surrounded by an inflammatory red area in the skin around the angles of the mouth. In the absence of this vitamin growth is retarded (Fig. 27.4).

Nicotinic acid or *niacin* is related chemically to nicotine present in tobacco leaf but has little or no toxic action. Liver, kidney, brewer's yeast, wheat germ, soybean, and peanuts are the chief sources of this member of the B complex.

[3] Three other vitamins of the B complex may be mentioned—namely, *pyridoxin, pantothenic acid,* and *biotin.* Little is known of their actions upon man.

The lack of adequate amounts of nicotinic acid in the diet is the cause of pellagra, or of the main symptoms, at least, of this disease. Pellagra is a disease of the poor in southern districts of this continent and of southern Europe, whose diet consists principally of maize. Its chief features are red, inflamed patches on the skin (especially of parts exposed to the sun), gastric and intestinal disorders, and mental symptoms, sometimes culminating in mania.

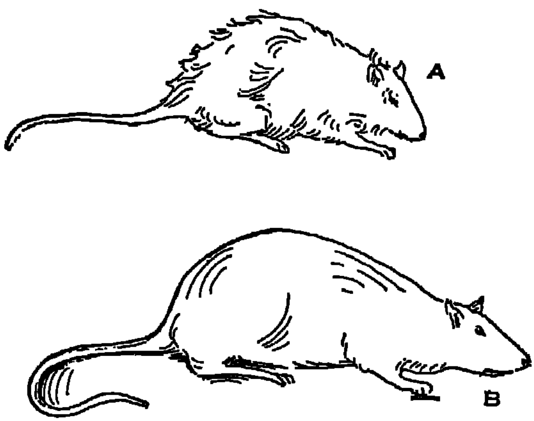


FIG. 27.4. The effect of riboflavin deficiency on growth. *A*, a rat fed a diet deficient in riboflavin and certain other factors of the vitamin B complex. Rat *B* received a normal diet.

Folic acid is a recent addition to the B complex. It is essential for the growth of certain bacteria, but, what is of much greater importance, it has been found to cure pernicious anemia, being about as effective as liver extract. It is found most abundantly in liver, spinach, and yeast. It has been synthesized.

Vitamin C, the antiscorbutic vitamin.—Deficiency of vitamin C is the cause of scurvy (scorbutus), a disease of which hemorrhages from the gums and other mucous membranes and into the bones and joints are the main features. This disease caused many deaths on the early voyages of discovery and was often a reason for the failure of exploring parties. Captain Cook has told of its ravages. Jacques Cartier (1535) on one of his voyages to Canada lost many men from scurvy until he was told by the Indians that a tea made from the young tips of evergreen branches was an effective remedy. James Lind (1747) deplored the prevalence of scurvy among British sailors and believed that it was due to the lack of fresh food, especially fruits and vegetables. His recommendation to the government

of the day that lime juice be supplied to all ships of the Royal Navy was eventually adopted with excellent results. Thus the sobriquet "lime-juicer," or "limey," for the British sailor had its origin. Even today, scurvy makes its appearance on exploration parties and dur-

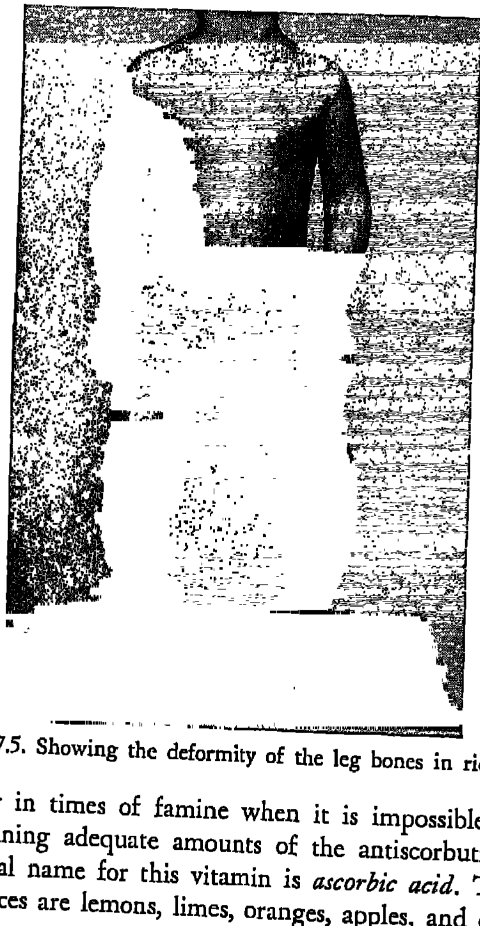


FIG. 27.5. Showing the deformity of the leg bones in rickets.

ing wars or in times of famine when it is impossible to obtain foods containing adequate amounts of the antiscorbutic vitamin. The chemical name for this vitamin is *ascorbic acid*. The richest natural sources are lemons, limes, oranges, apples, and other fresh fruit, turnips, tomatoes, and green vegetables. Ascorbic acid has been synthesized.

Vitamin D, the antirachitic vitamin.—Deficiency of this vitamin is the cause of rickets (rachitis), a disease of young children in which the bones have not the normal rigidity and strength because

they contain less than the required amount of mineral—calcium and phosphorus. Vitamin D is necessary for the concentration of these minerals as calcium phosphate in the growing bone. Deformities of the skeleton result (Fig. 27.5). Rickets is more likely to appear during the winter months than during the summer, because the sun's rays produce the vitamin in the skin of human subjects or of animals. Also the best food sources—fresh fish, eggs, and milk from cows which are receiving the vitamin in their diet—are more generally available in the summer months. This vitamin may be obtained in concentrated form in cod-liver oil or as *irradiated ergosterol* (viosterol). It is important that this vitamin should be supplied in adequate amounts to infants and young children if proper bone development is to take place.

Vitamin E, the antisterility vitamin.—Vitamin E has been shown in animal experiments to be essential for the normal functioning of the reproductive system. Female rats fail to give birth to living offspring if they are deprived of this vitamin. On a similar diet male rats become sterile. Vitamin E is found most abundantly in leafy vegetables and wheat germ.

Vitamin K, the antihemorrhagic vitamin.—When the body lacks this vitamin the prothrombin of the blood (p. 45) becomes reduced and, as a consequence, the coagulation of the blood is greatly delayed. Serious hemorrhages, therefore, may follow otherwise trivial wounds. This vitamin is synthesized in the intestine of many animals as well as of man. This means that it may be lacking from the diet with no ill effects. But the presence of bile in the intestine is necessary for its absorption. As a consequence, in jaundice due to obstruction of the bile passages vitamin K is not absorbed, the blood clotting mechanism is defective, and severe hemorrhage may result. Owing to this risk surgeons were reluctant to operate upon a severely jaundiced patient. Now the prothrombin concentration of the blood of such patients can be raised to normal before operation by injection of the vitamin or by giving an absorbable (water soluble) synthetic preparation of it by mouth.

Vitamin K is present in greatest amounts in green plants—e.g., clover and spinach—and in cauliflower and cabbage.

THE VITAMINS AND THEIR FUNCTIONS

Vitamin	Effects produced by deficiency of the vitamin	Human requirements per day	Food sources	Effects of cooking	For 1 day's requirement use all these foods or their equivalent
VITAMIN A	Decreased growth. Lessened resistance to infection. Poor vision in twilight or darkness. Xerophthalmia. Degeneration of nerves.	Children: 50 units per pound of body weight. Adults: 6,000 units.	Butter. Milk. Green leaf and yellow vegetables. Liver. Fish liver oils (such as cod or halibut).	Very slight.	3 glasses milk. 3 servings butter. 1 serving green leaf or yellow vegetables.
VITAMIN B see page 255					
VITAMIN C Ascorbic Acid or Antiscorbutic Vitamin	Scurvy: Hemorrhages due to weakening of blood vessel walls. Poor formation of bones and teeth.	Children: 800 units or 40 milligrams. Adults: 1200 units or 60 milligrams.	Tomatoes. Potatoes. Turnips. Green leaf vegetables. Most Canadian fruits. Citrus fruits.	Heavy loss if food is exposed to air. In commercial canning loss is slight. Serious loss in cooking water.	1 glass tomato juice (or 1 large serving canned or fresh tomatoes). 1 serving potatoes. 1 serving other vegetables.
VITAMIN D Antirachitic Vitamin	Rickets: Faulty formation of bones because of poor utilization of calcium and phosphorus.	Children: 500 units. Adults: Not known.	Vitamin D milk. Eggs. Fresh and canned sea fish. Fish liver oils (cod or halibut).	No effect.	In winter months particularly, children should have one teaspoon fish liver oil daily.
VITAMIN E	Possibly habitual abortion. In animals: Sterility in males and failure to complete pregnancy in females (not proven for humans).	Not known.	Whole-grain cereal products (especially wheat germ oil). Corn oil. Eggs. Meat. Green leaf vetegables.	No effect.	Cannot be stated because requirement unknown.
VITAMIN K Antihemorrhagic Vitamin	Hemorrhages, because blood does not clot normally.	Not known.	Green leaf vegetables. Tomatoes.	No effect.	Cannot be stated because requirement unknown.

MEMBERS OF VITAMIN B COMPLEX Thiamin, Vitamin B_1 or Antineuritic Vitamin	Decreased growth. Failure to use carbohydrates properly. A nerve disease leading to paralysis. Mental depression.	Infants: 100 units or 0.3 milligrams. Children and Adults: 500 units or 1.5 milligrams.	Whole-grain cereal products. Milk. Potatoes. Meat (especially pork). Eggs. Wheat germ. Yeast.	10 to 25% loss due to heat. Up to 50% loss in cooking water.	3 glasses milk. 6 slices vitamin-rich bread. 1 serving meat. 1 serving oatmeal or whole wheat cereal. 1 egg. 1 serving potatoes.
Riboflavin Vitamin B_2 or G	Decreased growth. Sores at corners of mouth. Inflammation of cornea of eyes, causing poor vision and sensitivity to bright light.	Children: 1.5 milligrams. Adults: 3 milligrams.	Milk. Eggs. Meat (especially liver). Green leaf vegetables.	No loss due to heat. There may be serious loss in cooking water.	3 glasses milk. 6 slices vitamin-rich bread. 1 egg. 1 serving meat. 1 serving green vegetable.
Nicotinic acid	Pellagra: Skin-rash, sore and inflamed tongue. Mental symptoms.	Children: 10 milligrams. Adults: 20 milligrams.	Meat. Fish. Milk. Green leaf vegetables. Eggs. Whole-grain cereal products. Yeast.	No loss due to heat. There may be serious loss in cooking water.	3 glasses milk. 1 serving meat. 6 slices vitamin-rich bread. 1 egg.
Pantothenic Acid	Deficiency symptoms in humans not known. In animals: Decreased growth, graying of black hair in rats and foxes.	Not known.	Milk. Liver and other meats. Eggs. Whole-grain cereal products. Peas. Potatoes.	No loss due to heat. There may be serious loss in cooking water.	Cannot be stated because requirement unknown.
Pyridoxine, Vitamin B_6	Deficiency symptoms in humans not known. In animals: Decreased growth, failure to use proteins properly.	Not known.	Meats (particularly liver). Whole-grain cereal products.	No loss due to heat. There may be serious loss in cooking water.	Cannot be stated because requirement unknown.
Folic acid	Not known but cures pernicious anemia.	Not known.	Liver. Green leaves.	Not known.	Not known.

chapter 28

THE PHYSIOLOGY OF THE KIDNEYS AND SKIN

THE KIDNEYS

Each human kidney is about 4 inches long, 2 inches wide, and a little over 1 inch thick. They are bean-shaped organs, lying one on each side of the vertebral column and covered behind by the lower ribs. The convex border of each kidney is directed outward and its concave border inward, that is, toward the vertebral column (Figs. 28.1 and 28.2). A large vessel—the renal artery—enters the center of the kidney's concave border and breaks up within its substance into short branches and finally into arterioles and capillaries. The blood is collected again by numerous small veins. These join together to form a single large vein—the *renal vein* —which leaves the kidney close to the point where

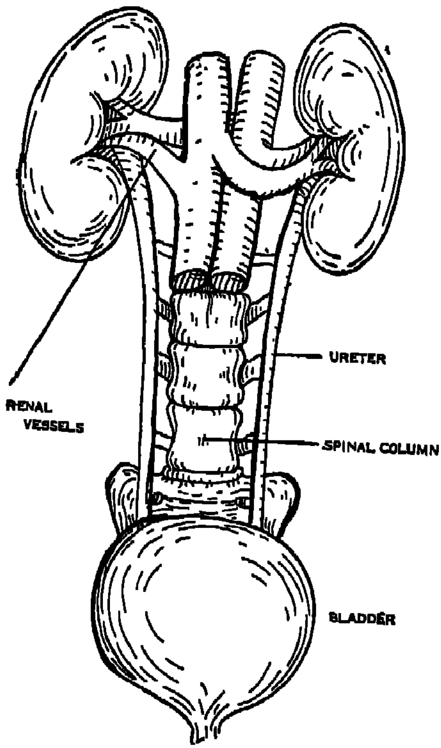


FIG. 28.1. The urinary system.

the artery entered. A third tube also leaves the kidney at the center of its concave margin. This tube, called the *ureter,* conducts the urine from the kidney to the bladder.

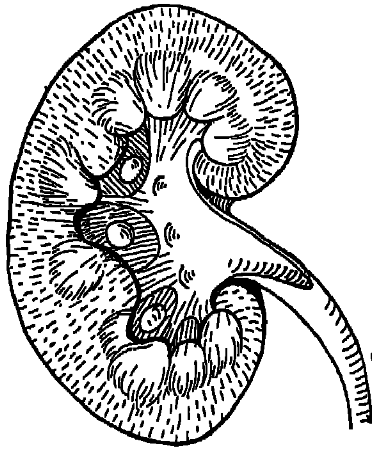


FIG. 28.2. A section lengthwise through the center of the kidney. The tubules which run their course through the substance of the kidney discharge the urine into the chamber (pelvis of the kidney) lying toward the concavity of the organ. This chamber is drained by the ureter.

The internal structure of the kidney.—The kidney contains great numbers of microscopic filters called *glomeruli* (singular *glomerulus*). There are about a million of these structures in each human kidney. Blood is carried to each glomerulus by a single arteriole. This *afferent* arteriole gives rise to about 50 capillaries which are bent into short loops; but the separate loops cannot be distinguished, the whole appearing as a tangled, red skein-like structure called the

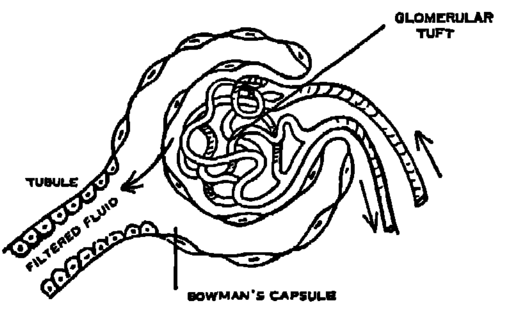


FIG. 28.3. The glomerulus of the kidney. The two arrows on the right indicate the flow of blood to and from the glomerular tuft. The third arrow indicates the passage of fluid from the blood into Bowman's capsule.

glomerular tuft. The capillary loops converge into a second fine vessel—the *efferent* arteriole—which carries the blood from the glomerulus. The glomerular tuft of capillaries is enclosed within

a two-layer membrane; the space or chamber between the two layers is called *Bowman's capsule* (Fig. 28.3). Into this chamber water, salts, sugar, etc., are filtered from the blood flowing through the capillaries of the tuft. Bowman's capsule is drained by a fine tube (the *renal tubule*), which after many twists and turns empties with

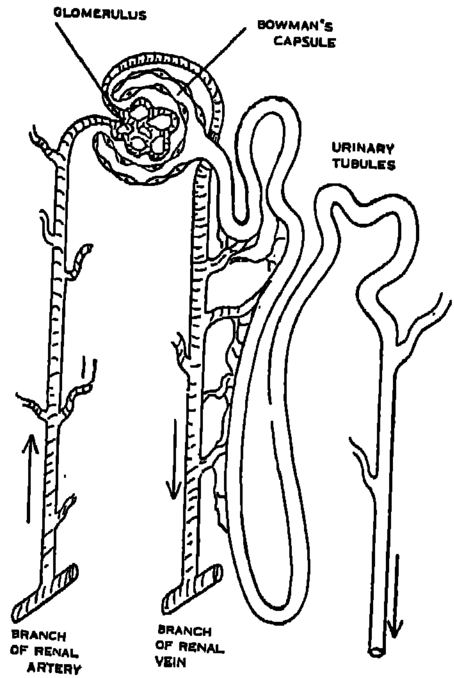


FIG. 28.4. The glomerulus and tubules of the kidney with their blood vessels.

other similar tubes into larger channels through which the urine ultimately reaches the ureter (Figs. 28.4 and 28.5).

Filtration through the glomerulus.—In the structure of the glomerulus are all the requirements of a perfect filter. A fluid containing solid material can be filtered off from such material by pouring it into a funnel lined by a cone of special paper (filter paper) which is permeable to the clear fluid itself but holds back the solids. The pressure of the fluid itself forces it through and thus brings about the separation. More elaborate filters have been devised in which

a membrane or a jelly is used instead of paper and the pressure on one of its surfaces is much greater than on the other. The glomerulus is such a filter. The fluid to be filtered is the blood, and the walls of the glomerular capillaries together with the layer of Bowman's capsule which covers them constitute the filtering membrane. The pressure of blood in the glomerular capillaries is much higher than that in any other capillary of the body. It amounts to 60 or 70 mm. Hg. The pressure on the other side of the membrane—that is, in Bowman's capsule—is only about 5 mm. Hg. The glomerular membrane offers a complete barrier to the passage of the blood cells. The membrane also prevents the large molecules of the colloids, i.e., the proteins, of the plasma from escaping into Bowman's capsule. The filtered fluid contains all the other constituents of the plasma and in the same concentrations as in the plasma. The fluid filtered into Bowman's capsule is therefore identical in composition with plasma which has been freed of its proteins.[1]

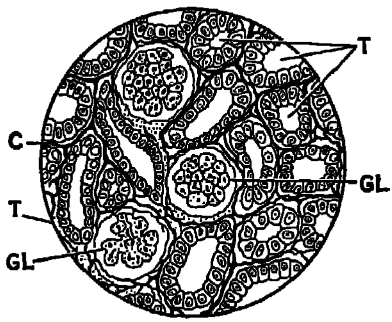


FIG. 28.5. Microscopic appearance of the kidney. *C*, dark lines representing capillaries; *Gl*, glomeruli; *T*, tubules.

Though each glomerulus filters a very small quantity of fluid in 24 hours, the volume filtered by all combined may amount to 150 quarts or more daily.

The concentration of the filtered fluid and the formation of urine.—The fluid filtered through the glomerular capillaries is *not* urine. The function of the kidney involves more than a simple process of filtration. The volume of the urine is only one seventieth or less of the volume of the fluid which enters Bowman's capsule. The

[1] This statement has been proved conclusively by analyzing a sample of fluid withdrawn under the microscope from Bowman's capsule by means of a very fine pipette.

urine is also much more concentrated than the filtered fluid—i.e., it contains more solids in solution, and the proportions of its various constituents are different. It contains no sugar, for example, but its concentration in such nitrogenous waste substances as urea, uric acid, and creatinine is many times greater than that of the fluid

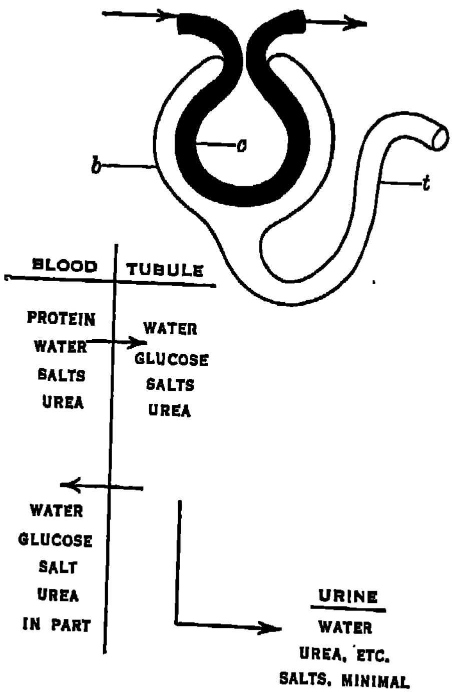


FIG. 28.6. Diagram to illustrate the filtration and reabsorption processes in the formation of urine by the kidney. *b*, Bowman's capsule; *c*, glomerular capillary; the arrows indicate the direction of the blood flow; *t*, tubule. *Below*, the constituents of plasma, filtrate, reabsorbed fluid, and urine are represented in tabular form. The arrows indicate the directions of their movements.

filtered from the blood. The conversion of this dilute fluid into the concentrated urine is brought about by the re-absorption into the blood from the tubules of water and of those essential materials which the body cannot afford to lose in unlimited amounts—namely, calcium, sodium, potassium, magnesium, and sugar. Though each tubule is only about 2 inches long and less than 1/60 inch in diameter, the combined length of all the tubules of one human kidney is about 40 miles and the total absorbing surface more than 6 square yards. Water and those substances which the tubules re-absorb and return to the blood in relatively large amounts

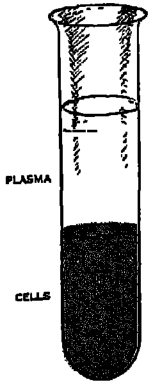


Plate I*a*. Blood after centrifuging, showing separation of plasma (55%) from cells (45%).

Plate I*b*. Red corpuscles in rouleaux.

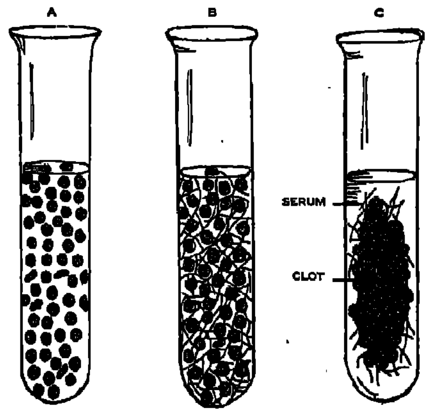


Plate I*c*. Showing the microscopic changes which occur during the clotting of the blood. *A*, before clotting had set in; *B*, formation of threads of fibrin; *C*, contraction (shortening) of the fibrin threads and trapping of the blood cells in the mesh. Diagrammatic.

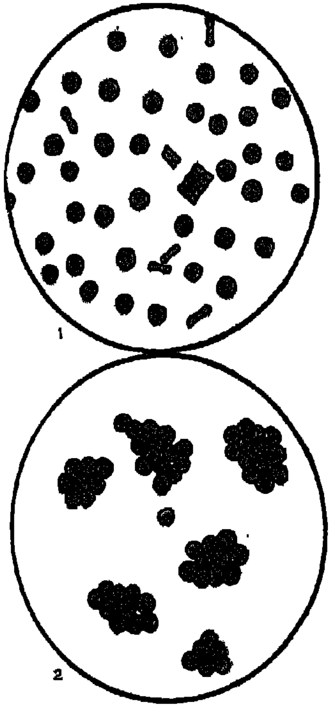


Plate I*d*. Showing agglutination of corpuscles by incompatible blood. 1. corpuscles of one subject mixed with compatible serum of another; 2. corpuscles mixed with incompatible serum; note agglutination.

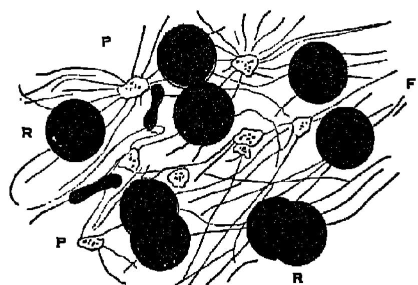


Plate I*e*. Showing *R*, erythrocytes; *P*, platelets; and *F*, fibrin threads formed in the clotting of blood. Note that the fibrin threads appear to radiate from the platelets.

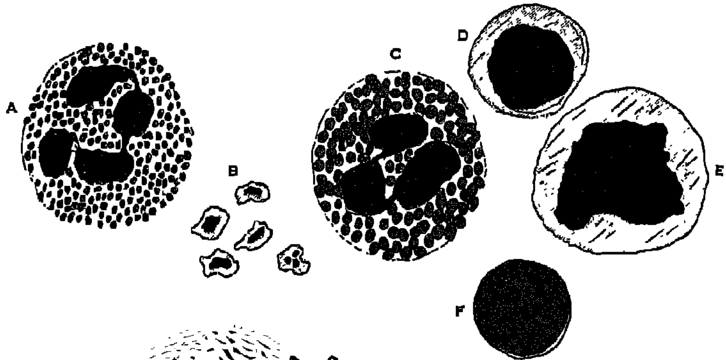


Plate II*a*. Showing the different types of blood cells. *A*, neutrophil; *B*, platelets; *C*, eosinophil; *D*, small lymphocyte; *E*, large lymphocyte; *F*, erythrocyte

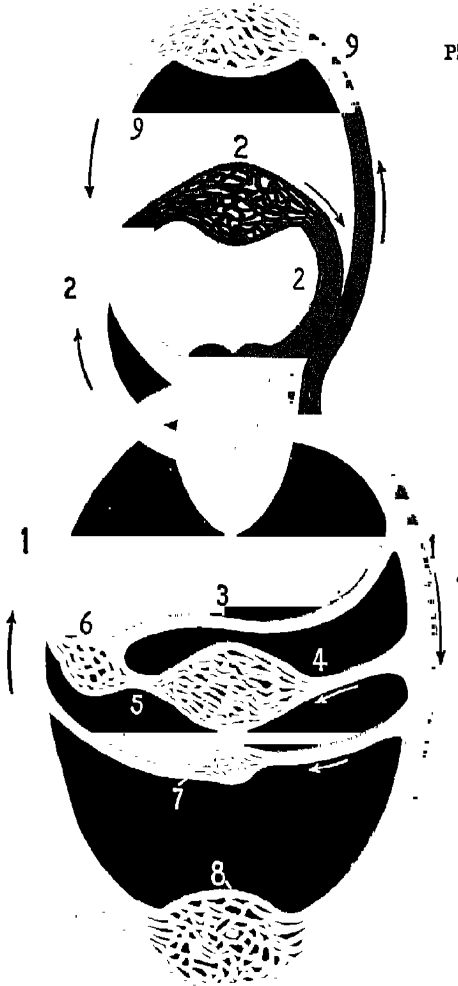


Plate II*b*. Diagram of the circulation of the blood. 1. Systemic circulation; 2. pulmonary circulation; 3. artery (hepatic) to liver; 4. arteries to most of the abdominal organs; 5. vein (portal) which drains blood from most of the abdominal organs; 6. circulation through the liver (hepatic circulation); 7. renal circulation; 8. vessels of the lower limbs; 9. vessels of the head and neck; *R.A.*, right auricle; *R.V.*, right ventricle; *L.A.*, left auricle; *L.V.*, left ventricle. The vessels to the arm are not shown. The main artery arises from the aorta close to the heart.

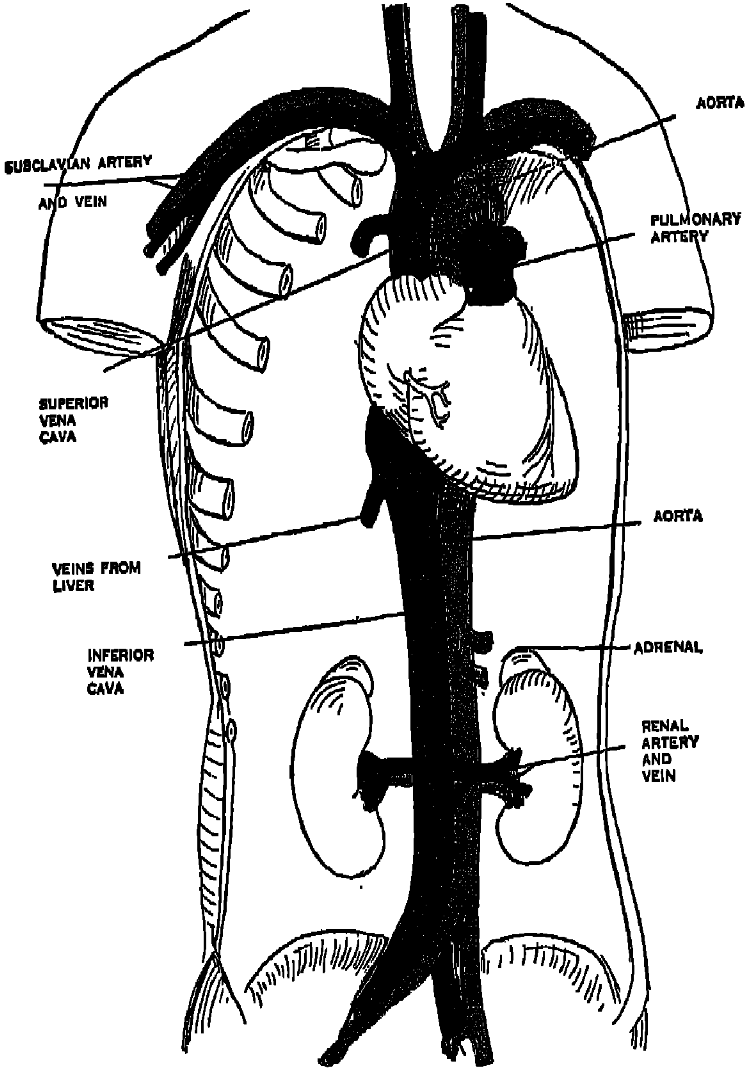


Plate III*a*. The large blood vessels. The pulmonary veins, four in number, which carry blood from the lungs to the left side of the heart, are hidden behind the aorta and pulmonary artery.

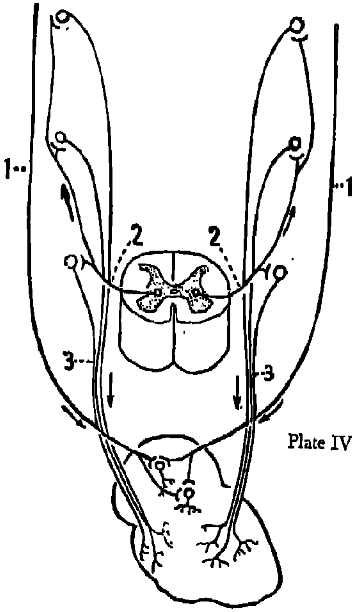


Plate IV*b*. Showing corpuscles in the capillaries of the web of a frog's foot.

Plate IV*a*. Diagram of the nerves which pass from the brain and spinal cord to the heart. 1. Vagus (of parasympathetic, p. 316); 2. accelerator fibers leaving the cord (sympathetic preganglionic fibers, p. 314) to connect with cells of sympathetic ganglia; 3. accelerator fibers from ganglia to the heart muscle (sympathetic postganglionic fibers). Note that the postganglionic fibers of the vagus arise from ganglion cells in the walls of the heart itself. Arrows indicate the course taken by the nerve impulses.

Plate IV*c* The coronary arteries. They are the first branches of the large artery (aorta) which receives the blood from the left ventricle. Veins (coronary veins) accompany the arteries but are not shown in the figure.

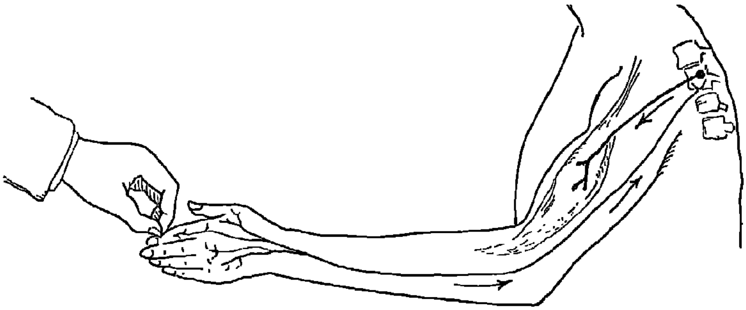


Plate V*a*. Showing the manner in which a reflex movement is brought about. When the finger is pricked or stimulated painfully in any way, impulses pass to the spinal cord by sensory (afferent) nerves where fresh impulses are set up in the nerve cells of the spinal center and transmitted to the muscles by motor (efferent) nerves.

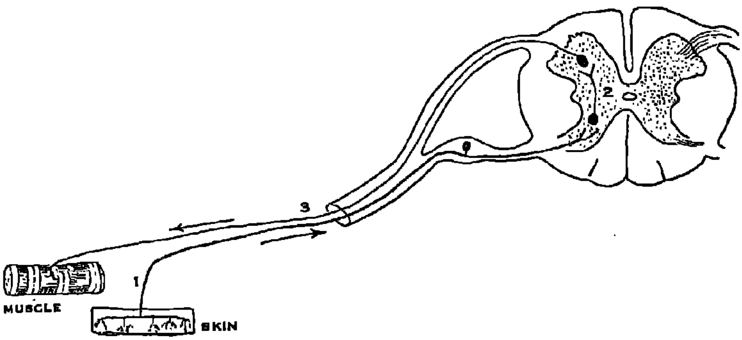


Plate V*b*. Showing a reflex arc. Arrows indicate the course taken by the impulses, afferent fiber in *red*, efferent in *black*. 1. receptor neuron; 2. connector neuron; 3. effector neuron.

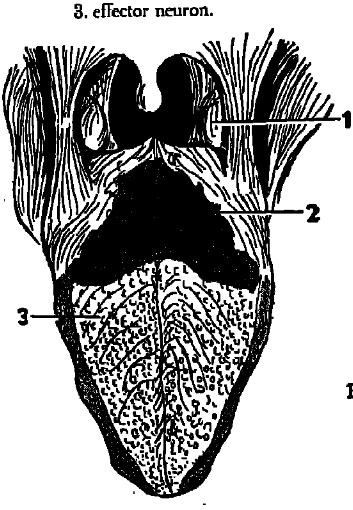


Plate V*c*. Map of tongue showing fundamental taste sensations. *Yellow* sweet and salty; *blue* acid; *green* bitter. 1. tonsil; 2. large papillae (circumvallate); 3. small papillae (fungiform) which give a velvety appearance to the surface of the tongue.

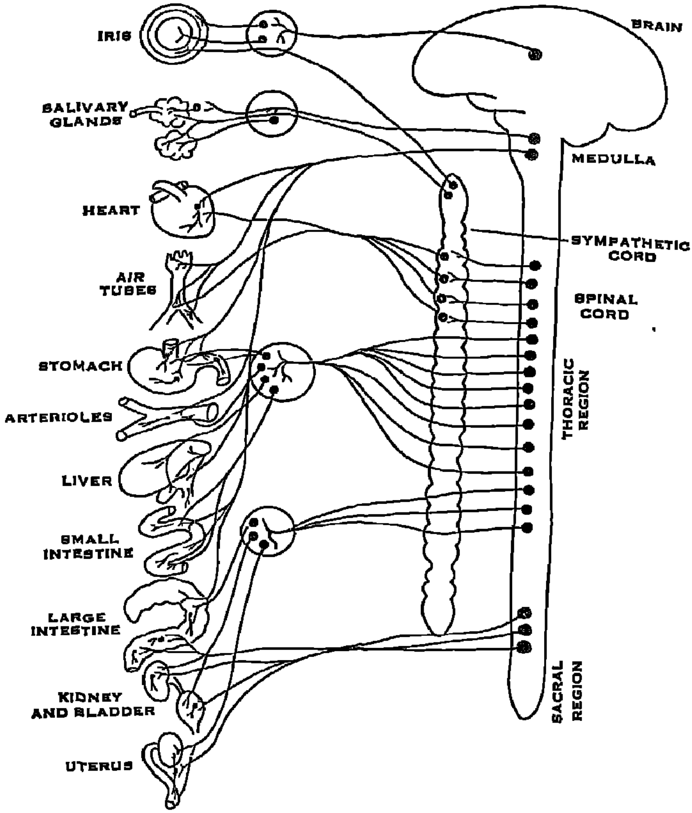


Plate VI*a*. The autonomic nervous system. Sympathetic division shown in *black*, parasympathetic division in *red*.

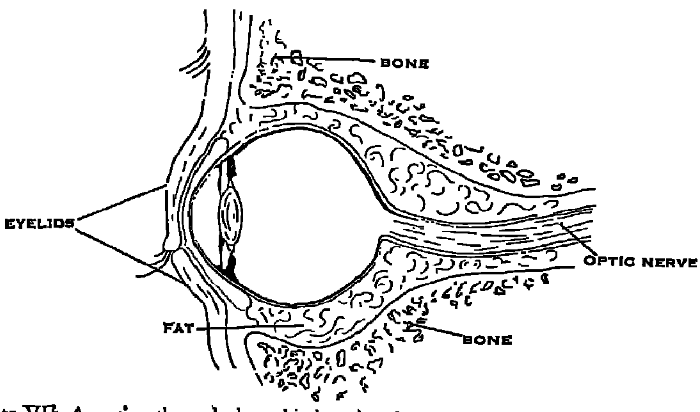


Plate VI*b*. A section through the orbital cavity showing the eyeball, optic nerve, and surrounding parts. Conjunctiva in *red*.

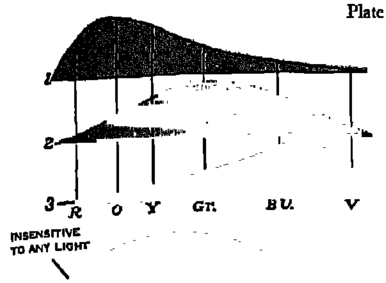


Plate VII*a*. Diagram of the three primary color sensations (Young-Helmholtz theory). 1. Represents the *red*. 2. the *green*; and 3. the *blue* color sensation. The lettering along the base line indicates the colors of the spectrum. The diagram indicates by the height of the curve at which it is cut by the vertical lines the extent to which the several primary sensations of color are excited by vibrations of different wave lengths. (*After Helmholtz.*)

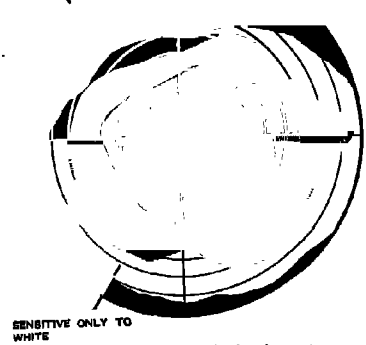


Plate VII*b*. Showing the distribution of color perception in the retina. Note that the area for *green* is the smallest, that for *blue* the largest.

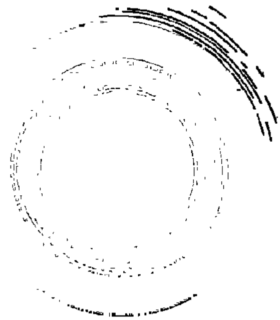


Plate VII*c*. Diagram of the color areas of the retina. See page 347.

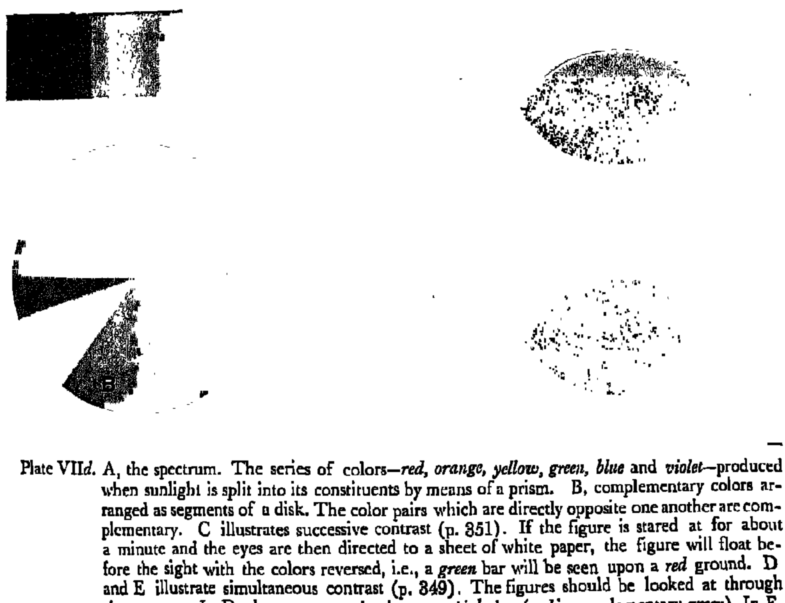


Plate VII*d*. A, the spectrum. The series of colors—*red, orange, yellow, green, blue* and *violet*—produced when sunlight is split into its constituents by means of a prism. B, complementary colors arranged as segments of a disk. The color pairs which are directly opposite one another are complementary. C illustrates successive contrast (p. 351). If the figure is stared at for about a minute and the eyes are then directed to a sheet of white paper, the figure will float before the sight with the colors reversed, i.e., a *green* bar will be seen upon a *red* ground. D and E illustrate simultaneous contrast (p. 349). The figures should be looked at through tissue paper. In D the *gray* ground takes on a *pink* tint (*red* is complementary *green*). In E the *gray* takes on a faintly *yellow* tint (*yellow* is complementary to *blue*).

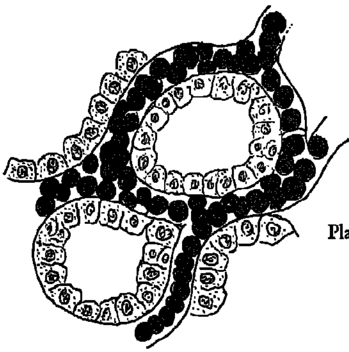


Plate VIII*a*. Showing two alveoli (acini) of a ductless gland and their relation to the blood in the capillaries.

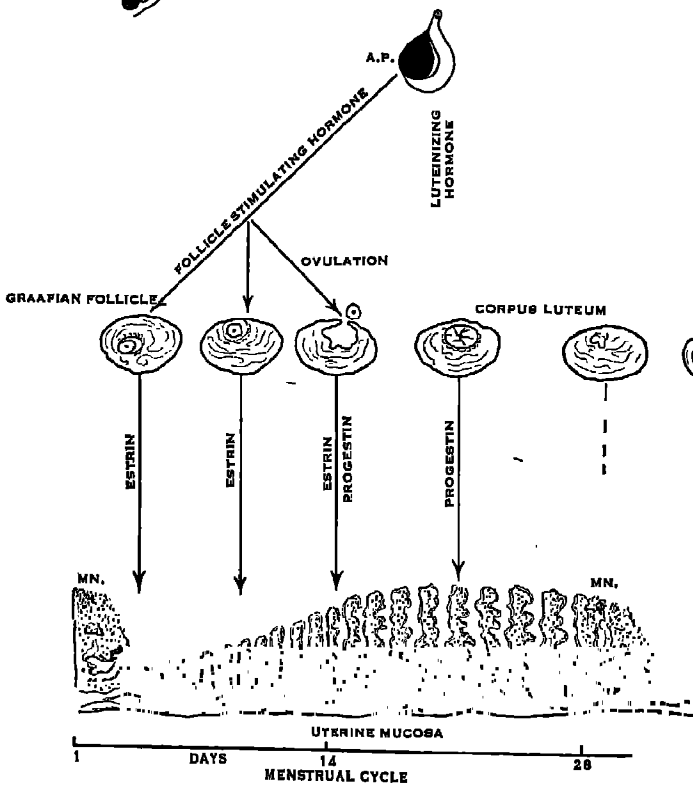


Plate VIII*b*. Showing the direct control of ovarian activity (growth of Graafian follicle and production of hormones) by the anterior lobe of the pituitary (*A.P.*) and secondarily, through the liberation of the hormones of the ovary, upon the rhythmical changes in the uterus leading to menstruation (*Mn.*). Note the thickening of the mucous membrane of the uterus and the growth of its glands. If the ovum after its escape from the ovary (ovulation) becomes fertilized, it embeds itself in the mucous membrane of the uterus and develops into the embryo; the corpus luteum then does not degenerate but continues to grow until it reaches a diameter in the human of nearly an inch. Such growth is essential for the continuance of pregnancy.

—namely, sugar and the essential minerals—are called *high-threshold* substances, which means that they are excreted in the urine in small amounts or not at all unless they are in abnormally high concentration in the blood. Those substances which the body discards and which are concentrated in the urine—that is, waste materials such as urea, uric acid, etc.—are called *low-* or *non-threshold* materials (Fig. 28.6).

The quantity of water absorbed from the tubules amounts to 98 or 99 percent of the total volume of fluid filtered from the plasma. Thus if 2 quarts of urine are formed in 24 hours something in the neighborhood of 150 quarts of fluid have been removed from the plasma, and 148 quarts or so have been re-absorbed from the tubules.

Other functions of the kidney.—The formation of urine is, of course, very closely bound up with the kidney's really essential function of regulating the composition of the blood. By excreting acids and preventing the loss of bases it is an important factor in maintaining the alkalinity of the blood and other fluids of the body. The fluid filtered into Bowman's capsule, is alkaline in reaction like the plasma, but in passing along the tubules base is returned to the blood and the urine becomes acid. The kidney also serves to render certain toxic substances innocuous. Finally, it produces and excretes ammonia combined with acids.

The quantity and composition of the urine.—The adult human body excretes on the average from ½ to 2 quarts of urine in 24 hours. The amount varies, of course, with the amount of fluid drunk and that lost through the skin and intestines. A rise in blood pressure in the vessels of the kidney, since it increases the filtration force in the glomerulus, increases the amount of urine formed. Dilatation of the capillaries in the glomerulus also increases urine production because the total filtering surface is then increased. That is the reason why certain substances such as coffee or tea increase the urinary flow. They contain caffeine, which dilates the renal vessels. Cold constricts the vessels of the skin and causes more blood in consequence to flow through the kidney. In these circumstances the urine is also increased in amount. (See also p. 233.)

The urine is slightly acid in reaction. The chief substances which it contains are:

Urea	Magnesium
Uric acid	Chlorides
Creatinine	Phosphates
Sodium	Sulfates
Potassium	Amino acids
Calcium	

Drugs and other substances taken into the body and not required are promptly excreted in the urine. Certain dyes pass from the body in the urine, staining it various colors. Patent-medicine manufacturers make use of this fact and put dyes into their pills to impress and fool the unwary public. Another practice of the patent-medicine advertiser is to try to convince the public that pain in the back is a sign of kidney disease. The kidney, when diseased, very rarely gives such a sign. We all at some time or other have suffered from back pain, but this usually arises from the muscles attached to the spine and is not due to any abnormal condition of the kidney.

Though, as mentioned above, the protein of the blood does not in health appear in the urine, in kidney disease the membranes of the kidney may have become so deteriorated that protein material (usually albumin) and sometimes red cells "leak" into Bowman's capsule. These abnormal constituents can be detected by special means. In diabetes the amount of sugar (glucose) in the blood is much greater than normal. The kidney tries to remove the excess, and large quantities of glucose are passed in the urine. As mentioned above, the urine of a healthy person is practically free from sugar.

The Skin and Mucous Membranes

The skin forms a complete covering for the outer surface of the body. The digestive and respiratory tracts, and other tubes or cavities which open into the digestive tract or to the outside world, are lined by a soft, dark red, velvety tissue called mucous membrane.

The structure of the skin.—Next to the bones, the skin and the structures which grow from it, such as the nails of man and the claws, horns, and hoofs of animals, are the firmest and toughest tissues of the body.

If a thin wafer of skin is cut perpendicularly to the surface and examined under the microscope, several layers of closely packed cells

will be seen (see Fig. 28.7). The outer layers of cells are flat and resemble scales (squamous epithelium). They are firm and hard (*horny layer*). The deeper layers of cells are more rounded in shape and become irregularly massed together to form tongues which project into the *true skin* below. The very deepest cell layers are tall and are filled with a dark *pigment,* which is greater in amount in some persons than in others and also varies greatly in different races. The skins of dark races such as the African Negro have large amounts of this pigment; the Indian, Chinese, and Japanese have less; and the white races have least. All the layers of skin described above are together called the *epidermis* or *cuticle*. No blood vessels or nerves are found in any of these layers, and the outermost cells are being continually shed to be replaced by others which move up from below.

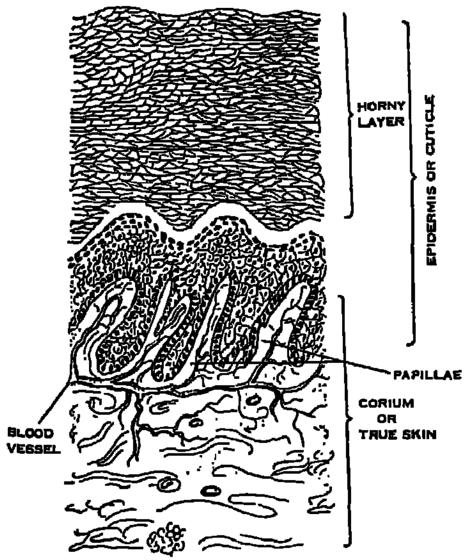


FIG. 28.7. Showing the several layers of the skin (highly magnified).

The thickness of the epidermis is different in the various regions of the body; on the eyelids, for instance, it is no more than $\frac{1}{100}$ inch thick. On the soles of the feet or palms of the hands, especially in one who performs hard manual labor, it may be $\frac{1}{10}$ inch thick or more.

Beneath the cuticle is a meshwork of connective tissue fibers, which are very elastic. For this reason the skin, as we know, can be stretched very easily, and when released it quickly springs back again into place. This deep part of the skin is called the *corium* or *true skin*. It is heaped up into mounds or hillocks (*papillae*), which lie between the projecting tongues of the overlying cuticle. In it are found blood vessels, nerves, and sweat glands. Beneath

the true skin is a layer of fatty tissue. This fatty layer is much thicker in some parts of the body than in others and serves as a padding to round out certain unevennesses in the body surface or to cushion its bony parts. The amount of fat also varies in different people, a fact with which everyone is familiar.

The hairs.—The skin over all regions of the body, with very few exceptions, such as the palms of the hands and soles of the feet, is covered with hairs. Except in certain regions, such as the

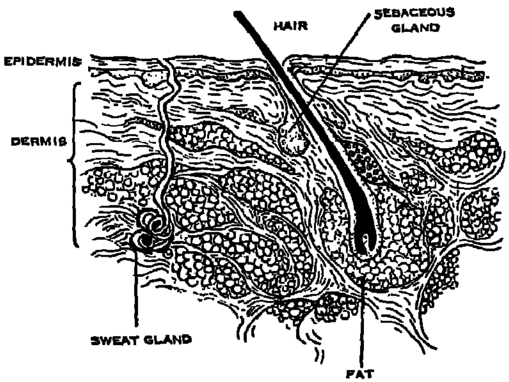


FIG. 28.8. A section of skin showing hair follicles and sebaceous and sweat glands. (Lower magnification than Figure 28.7.)

scalp and the faces of men, they are very fine and short. The part of the hair which we see above the skin is called the *shaft;* the part lying below the skin surface is called the *root.* Each hair has its root planted deeply in the true skin or in the layer of fat beneath this. The root runs obliquely upward through the cuticle and is completely enclosed in a little tube called the *hair follicle* (Figs. 28.8 and 28.9). The shaft, or visible part of the hair, does not rise straight up from the surface of the skin, but is slanting, like a blade of grass blown by a breeze. The hairs in any one part of the body all slant in the same direction. A network of fine nerves surrounds the hair follicle where it lies in the true skin, and that is why pulling the hairs is so painful. The organs of touch (p. 393) lie in the true skin close to the hair follicle—just beneath that region of cuticle which lies on the "windward" side of the hair shaft. Hence a slight movement of the tips of the hairs causes a sensation of touch, because the movement stimulates the neighboring touch organ. Small glands (*sebaceous glands*) in the true skin pour an

oily material into the hair follicles, which lubricates the hairs and oozes out on the surface of the skin.

The sweat glands.—These are tiny coiled tubes lined with cells which draw fluid from the blood to form a secretion, called *sweat* or *perspiration*. The little gland lies in the true skin, but it sends its secretion along a spiral tube which passes through the cuticle and

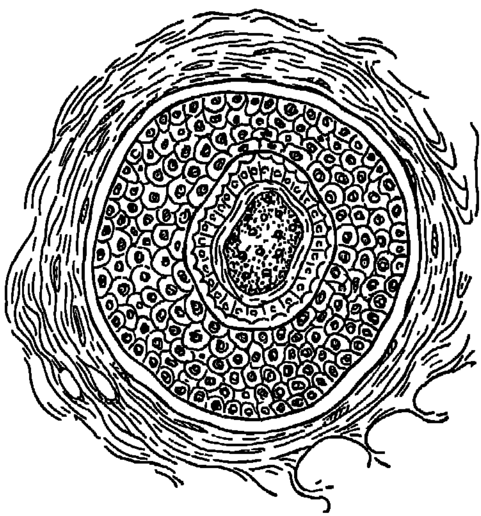


FIG. 28.9. A cross section of a hair root.

opens by a small mouth upon the surface of the skin. The mouths of the sweat glands are often called the "pores" of the skin.

The nails.—The human nails, the claws, horns, and hoofs of animals, the antlers of stags, and the horn of the rhinoceros are simply the cuticle of the skin which has been hardened and otherwise changed in character. The nails and the hard structures just mentioned grow from the true skin. The *root* of the nail is the buried part covered by ordinary cuticle (Fig. 28.10). In the root the cells forming the soft deeper layers of the skin, as they grow outward, are turned into the stiff and hardened type so characteristic of the horny material of well-formed nails. The claws and hoofs of animals also each have a root where this change takes place.

The functions of the skin and mucous membranes.—The skin has three important functions to perform. These are (1) protection,

(2) excretion, and (3) the regulation of body temperature. The firm, insensitive cuticle protects from injury the underlying delicate tissues, with their sensitive nerves and important blood vessels. How exquisitely sensitive the flesh is, when the outer layers of skin have been removed after a burn or blister, is known to us all. The hard, resisting outer layer of skin and the mucous membranes also serve as barriers against most microorganisms. Once one of these barriers is broken down by some injury, such as a cut or a burn, bacteria, which are everywhere about us, find the weakened spot in the body's defenses. It is of the greatest importance, therefore, that any opening in the skin be thoroughly cleansed to rid it of any infection which may have found a foothold. A dressing must then be put on to prevent any other bacteria from getting in (p. 59).

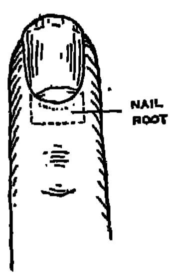


FIG. 28.10. The finger nail.

The body excretes its waste material chiefly through the lungs (carbon dioxide), the kidneys (urea, uric acid), and the bowels; but the skin, though much less important as an excretory organ than these three, nevertheless does excrete small amounts of waste materials. When, for any reason, the other organs fail in their excretory powers, the excretory functions of the skin increase. But even in health small quantities of carbon dioxide are given off by the blood through the skin, and the sweat carries away a little of the urea and uric acid. The mucous membrane of the bowel is a very important pathway along which many substances are excreted from the blood. Its absorptive functions have been spoken of elsewhere. The important part played by the skin in regulating the temperature of the body has been described (p. 233).

Skin, when its vessels are constricted together with the layer of fat lying beneath, possesses insulating qualities of a high order. It is comparable in this regard to a layer of cork of the same thickness. Thus heat is conserved in cold weather. In hot weather (as mentioned on p. 233) the cutaneous vessels dilate and heat is radiated from the blood to the surroundings. The evaporation of water secreted by the sweat glands is an additional means whereby heat is dissipated (p. 234).

part VII

The Nervous System

chapter 29

THE MICROSCOPIC STRUCTURE OF THE NERVOUS SYSTEM. THE NERVE IMPULSE. RECEPTORS. THE NATURE OF SENSATION

THE MICROSCOPIC STRUCTURE OF THE NERVOUS SYSTEM

Not until the microscope had been discovered could even the faintest idea of the texture of the nervous tissue be formed. And not, of course, until it was known how nervous tissue was composed could any knowledge of the functions of the nervous system be gained. The central nervous system (brain and spinal cord) is made up of a vast number of nerve cells, bound together by a special kind of connective tissue called *neuroglia.*

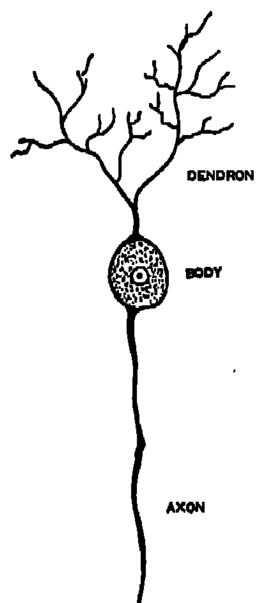


FIG. 29.1. A typical nerve cell.

The nerve cell.—The nerve cell (Fig. 29.1) is also called a *neurone.* It has a *body,* which may be rounded, pyramidal, oval, or star-shaped. The shapes and sizes vary in different regions of the central nervous system. Some nerve-cell bodies are quite large; others are small. The outstanding feature of nerve cells is their possession of two or more arms known as *processes.* The processes are of two kinds. One kind in its most typical form, but by no means invariably, is short with many branchings like the limbs of a

tree. For this reason it is called a *dendron, dendrite,* or the *dendritic process* (Gk. *dendron* = a tree). The dendron may be single, but more commonly the nerve cell possesses two or more. The other kind of process, which as a rule springs from the opposite pole of the cell, is called the *axon* or the *axis cylinder process.* In its typical form it is long and slender, but may be short with many branches. The axon is always single. The two processes—dendron and axon—are "one-way" lines. The dendron carries impulses to the cell body; the axon carries impulses from the cell body. Neither process transmits both ways. (See p. 280.) The nerve processes—axon and dendron—though often quite short, may be very long—several feet, indeed. The nerves of the body are simply great numbers of these long processes—now called fibers—bound together into cables.

The adjective *afferent* (L. *ad* = to; *fere* = to bear) is applied to processes of nerve cells, nerve fibers whether in the central nervous system or in the nerves, the nerves themselves, or the impulses, if they conduct or are conducted to the body of the nerve cell. We may therefore speak of afferent fibers, impulses, etc. If conduction is away from the cell body they are called *efferent.* Thus, sensory nerves—e.g., nerves of touch, pain, sight, etc.—are composed of afferent fibers or dendrons. Nerves which carry impulses to muscles and glands are called efferent; they are composed of axons.

A word must be said about the main features of the minute structure of the nerve-cell body. Like almost all cells in the animal body it possesses a nucleus, which is situated usually at or near its center. The surrounding protoplasm when stained with certain dyes shows numerous small, dark, angular flecks of granular material. They are known as *Nissl bodies.* They are arranged roughly in rows which give a striped tiger-skin appearance to the body of the cell and on this account are sometimes referred to collectively as the tigroid substance. The Nissl bodies are most pronounced in the resting cell; during activity they become reduced in number and in the fatigued or exhausted cell may disappear entirely for a time. Very fine lines are to be seen streaming into the body of the cell from the axon and dendrons. They are known as *neurofibrils* and form a delicate network in the protoplasm (Fig. 29.2).

The gray matter of the brain and spinal cord is made up of millions of nerve-cell bodies packed closely together (p. 279). The white matter is simply the processes or fibers of these cells, massed

into bundles, ropes, and cables (p. 292), which serve either to connect some part of the nervous system (brain or cord) with another (*association fibers*), or are on their way to leave the brain or cord by the various cranial or spinal nerves (*projection fibers*).

A more or less circumscribed group of nerve cells with common functions, such as those which give rise to the fibers composing one or other of the cranial nerves, is called a *nucleus*.

The nerve fiber.—Each fiber in a nerve trunk, which as mentioned above is a process of a nerve cell, consists of a central core called the *axis cylinder* and a sheath of fatty material (*sheath of Schwann*) which serves to insulate the fiber from its neighbors. Outside the fatty sheath is an enveloping membrane called the *neurilemma*.

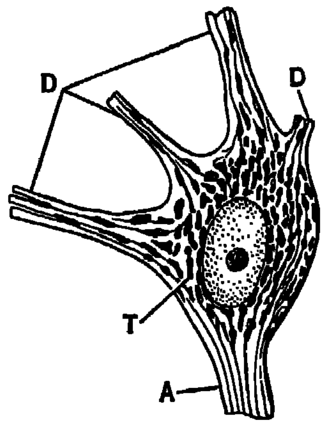


FIG. 29.2. Minute structure of the body of a nerve cell. *A*, axon; *D*, dendrites cut across; *T*, tigroid substance or Nissl bodies.

The nerve impulse.—The changes which take place in and travel along a stimulated nerve are referred to as the *nerve impulse*. Much remains to be learned concerning the impulse, but we do know that it is invariably accompanied by an electrical effect—a change in electrical potential. If a nerve is connected with an instrument (such as a galvanometer) which will record small electrical changes, the currents set up in the nerve when it is stimulated can be picked up and recorded photographically. The curve shown in Figure 29.3 is such a record from the sciatic nerve of a frog. If the passage of the impulse between two points on a nerve is timed, its speed can be calculated. This amounts to about 100 yards per second in one of the large nerves of higher animals, but is much slower in the nerves of the frog and other cold-blooded animals.

The frequency of the impulses—that is, the number of impulses which travel along the nerve per second—varies widely, from 10 to 1,000, according to the particular nerve which is stimulated and the strength of the stimulus. The impulse frequency rises with increasing strength of stimulus. *No change in the magnitude of the*

impulse results from varying the strength of the stimulus. There is a definite upper limit to the rate at which the nerve fiber can conduct impulses, because for a brief time after the impulse has passed, the nerve will not transmit a second impulse. This period of unresponsiveness is called the *absolute refractory period.*[1] It has a duration of only 1/1000 second or less in mammalian nerve. One

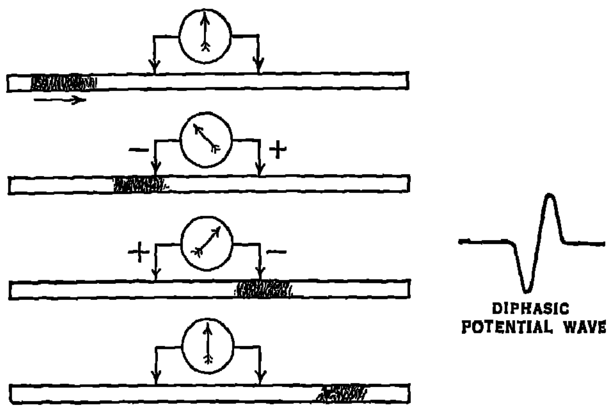


FIG. 29.3. A record of the electrical change which accompanies the nerve impulse. Electrical contacts are placed upon the nerve and connected through a galvanometer (as represented by the arrow within the circle). The movement of the indicator of the galvanometer (as represented by the arrow) is recorded photographically. The double (diphasic) curve on the right is the type of record obtained. The dark area on the nerve represents the nerve impulse; i.e., the excited part of the nerve at successive intervals of time.

thousand per second is, therefore, the theoretically maximal rate at which impulses can be transmitted along the nerve (Fig. 29.4).

The reader may have gained the impression that the nerve impulse is simply an electric current and the nerve fiber an inert conductor. But though the impulse is invariably accompanied by an electrical change and much information has been acquired from the study of electrical records, it is not merely an electric current, for it is propagated at a much slower rate. An electric current travels at the speed of light. The nerve fiber is not an inert conductor. Not

[1] Following the absolute refractory period is a brief interval of time during which the nerve, though it will respond to a stimulus, is less excitable than normally, as is shown by the relatively small magnitude of the electrical record. This interval is called the *relative refractory period.*

only is it a living structure but it shows metabolic changes during activity, and the transmission of the nerve impulse is dependent upon these changes. The nerve consumes more oxygen and produces more carbon dioxide during activity—that is during the passage of the impulse—than during rest.

In the mode of its propagation the nerve impulse is more like a spark traveling along a fuse of gunpowder than an electric current,

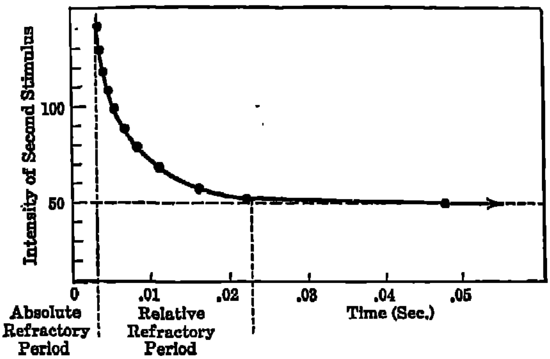


FIG. 29.4. Curve of the recovery in the sciatic nerve of the frog. Two stimuli were applied to the nerve in a series of tests, the second stimulus in each instance being separated from the first by various time intervals and of just sufficient strength to excite. Intensity of stimulus is plotted along the vertical, time along the horizontal. The interrupted horizontal line indicates the strength of current required to excite the *resting* nerve. During the absolute refractory period (about 0.003 sec. in this instance) a stimulus, however strong, will not excite. The excitability returns gradually during the next 0.02 sec. (relative refractory period). (*After Adrian.*)

for it and the spark derive the energy for their transmission from the path along which they travel. An electric current is generated, not in the conducting wire but in a battery or dynamo and merely conducted by the wire. If a small section of a fuse of gunpowder is slightly dampened somewhere along its course and one end of the fuse then lighted, a spark or flame is started which travels rapidly until it reaches the dampened portion. It progresses more slowly and with difficulty through this region, burning feebly, perhaps spluttering, and may become almost extinguished. The nerve impulse behaves in a way essentially similar. It too depends for its propagation upon energy-yielding materials in its path—the nerve

fiber. If a section of nerve is treated with a chemical which depresses its metabolic processes, such as chloroform, ether, or alcohol, but does not cause a complete block, the impulse upon arriving at this section is impeded. It travels more slowly and its magnitude, as indicated by the electrical record, is greatly reduced. When it reaches the untreated part of the nerve beyond the depressed region, which is comparable to the dampened section of the gunpowder fuse, its original strength and velocity are regained. Now, a wire

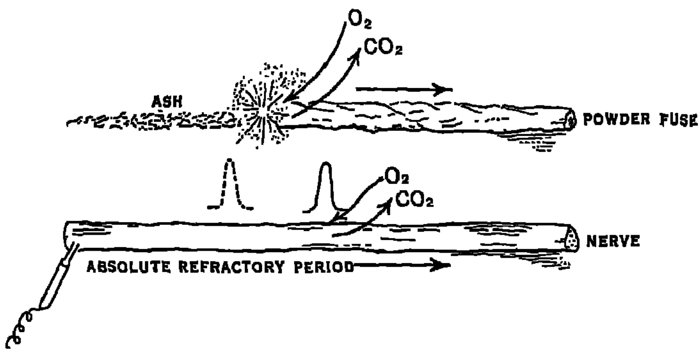


Fig. 29.5. A comparison of a spark traveling along a fuse of gunpowder with the nerve impulse. The arrows indicate the direction of transmission.

transmits an electric current in an entirely different way, for if some resistance is placed in its path its strength is reduced but is not restored after the resistance has been passed (Fig. 29.5).

Other comparisons can be drawn with profit between the fuse of gunpowder and the nerve fiber. The spark progresses because it is able to heat and then ignite successively the sections of fuse immediately ahead of it. So too the electrical current accompanying the nerve impulse serves to stimulate the part of the nerve just in front. Thus both the spark and the nerve impulse are self-propagating. After the spark has passed nothing remains but a trail of ash, which of course is incombustible. Fresh powder must be laid before another spark can be started on its way. This after-state of the fuse corresponds to the refractory period of the nerve fiber; but, unlike the fuse of gunpowder, the nerve fiber itself restores within a small fraction of a second the materials necessary for the propagation of another impulse. Again, the size of the spark, the speed at which it travels, and the amount of heat which is generated are

not influenced at all by the size or heat of the flame used to light the fuse. So long as the heat applied is sufficient to ignite the powder it is immaterial whether an electric spark, an ordinary match, or a blowtorch is used. So it is with the nerve fiber; any stimulus strong enough to excite the nerve at all, under the conditions existing at the moment, causes a maximal impulse to be set up. This is known as the *all-or-nothing law;* its application is not confined to the excitation of nerve but holds true for other excitable tissues as well—e.g., muscle.

Receptors. How the Nerves Pick up Messages from the World Around Us

The sensory cranial nerves carry to the brain messages (nerve impulses) which, upon reaching our consciousness, give information concerning the outside world. The nerves of sight (optic) carry messages from the eye, and the nerves of hearing (auditory) messages from the ear. The nerves of smell (olfactory) bring information from the nose, and the nerves of taste information from the mouth. All these nerves run directly to the brain and for the greater part of their courses run within the skull or cranium. Many other sensory nerves (spinal sensory nerves), such as those coming from the skin and causing sensations of pain, heat and cold, touch—that is, the nerves through which we feel—do not run to the brain directly. They run into the spinal cord (p. 292). Some of their fibers then separate and run upward in the cord by different routes to reach the brain.

But the sensory nerves, even those to the skin, do not end simply as bare branches. Each fine terminal of a sensory nerve is surrounded by a tiny structure, often a single cell, which is especially designed to receive stimuli and to set up impulses in the nerve fiber to which it is attached. These specialized "end organs" are called *receptors.* Each type of sensory nerve has its own particular type of receptor, which differs in structure from all other types and responds effectively to but one form of stimulation. For example, the receptors of sight—the rods and cones of the retina—are stimulated by light (p. 328); those of hearing, which are contained in the basilar membrane of the internal ear, respond to sound vibrations (p. 374); and those of pain, touch, and heat and cold, situated in

the deeper layers of the skin, are excited by mechanical forms of stimulation or changes in temperature (p. 373). The receptors of smell and of taste are especially designed for the reception of chemical forms of stimulation—that is, when odorous substances (in gaseous form) or substances possessing taste come into contact with them.

It should be pointed out, however, that a receptor, though it possesses a very special ability to respond, by the creation of nerve impulses, to only one type of stimulus, will respond in an imperfect way to other forms of stimulation for which it is not especially adapted. For example, though the receptors in the retina are stimulated most effectively by the waves of light, and no other receptor has this ability, they may be stimulated mechanically, as by a blow upon the eyeball, when flashes of light are experienced. A blow upon the ear will cause ringing, humming, or other auditory sensations, and an electric current applied to the tongue arouses a metallic taste. Stimulation of the bare optic nerve itself or of the nerve of hearing (acoustic nerve) will also cause a sensation which is a crude imitation of that produced by the corresponding receptors. These facts are exemplified by the behavior of an electrical instrument such as the telephone. The transmitter is especially designed to receive and respond to sound waves, but rubbing or tapping the diaphragm will also produce electrical impulses, which travel along the wire and produce harsh and meaningless sounds in the receiver at the other end.

Receptors such as those mentioned which receive stimuli from the outside world are called *exteroceptors*. But there is another type which is stimulated by changes within our own bodies. These are called *proprioceptors* and are situated in the walls of the stomach and intestines, in the heart and large blood vessels, and in the muscles, tendons, and joints and the internal ear (p. 374). Many proprioceptors give rise to impulses which make no impression upon our consciousness (non-sensory impulses); they give secret information to the central nervous system. Through them many reflex acts are brought about. Those in the muscles, tendons, and joints and in the internal ear are stimulated by movements of the structures in which they lie. Through them both sensory and non-sensory impulses are discharged along the nerves which they serve. Thus, the central nervous system is constantly informed of the

movements and positions of the different parts of the body and of the body as a whole in space.

The impulses carried to the central nervous system along the various sensory nerves do not all have the same destination, but each type of nerve—whether of sight, hearing, touch, etc.—conveys its impulses to some particular part of the cerebral cortex. These cortical regions are called *areas* or *centers.*

The Nature of Our Sensations

Should we examine the different nerves very closely, we would find that they all looked very much the same. Even if we took a thin slice from each and compared these slices under the microscope, we should find that each was made of a number of fibers which appeared almost identical, no matter what nerve was being examined. Furthermore, when we study the electrical currents associated with the impulses of each kind of sensory nerve—optic, acoustic, etc.—no essential difference can be found between them. From every test that can be applied there is no reason to believe that the impulses are not the same in all nerves, including the motor nerves. How is it then that there are several very different sensations? We have seen that the differences do not depend upon the receptors, for stimulation of a bare nerve causes a sensation which though crude and disorganized is nevertheless characteristic. From these facts the conclusion is forced upon us that the quality of any sensation depends upon the aiea or center of the cerebral cortex where the impulses arrive. The nerve cells in each of these areas interpret in their own way, and quite beyond our understanding, the impulses which they receive. Indeed, in disease one of these cortical areas may be stimulated *directly,* not by impulses arriving by the usual pathways. Flashes of light, noises, or other halucinations may then be experienced by the patient.[2] Therefore, the sensation which we know as sight or hearing is not created in the eye or ear. These organs merely set up effective impulses. Impulses arriving in the center for sight (*occipital lobe*) are perceived as visual sensations, those in the auditory center (*temporal lobe*) as sensations of sound, and so on. It may, then, with truth be said

[2] By the electrical stimulation of different regions of the exposed brain of a conscious subject, various sensations can be produced.

that sight is a special function, not of the eye, but of the occipital lobe of the brain. Sound, likewise, is the sensation which the cells of the temporal lobe make of impulses, no matter how produced, arriving there. Our other sensations—taste, smell, and touch—are also due to different interpretations which other centers of the brain put upon the nerve impulses which they receive. Just as a bell, a glass jar, an iron bar, or a gong produces each its different tone when struck in turn by the same object, so the different centers of the brain give rise to different sensations, though the nerve impulses which each receives are similar. If, therefore, it were possible to connect the *eye* with the *temporal lobe,* and the *ear* with the *occipital lobe,* we would, as someone has expressed it, "hear the lightning and see the thunder."

chapter 30

THE FUNCTIONAL ORGANIZATION OF THE NERVOUS SYSTEM. REFLEX ACTION. RECIPROCAL INNERVATION

The Functional Organization of the Central Nervous System

There are something like twelve billion nerve cells in the human brain. We have seen that each nerve cell has two processes. Also many processes of cells in the spinal cord ascend to the brain. The white matter of the nervous system is, then, composed of an immense number of nerve fibers. Some of these fibers are very long for, as we know, many pass from the central nervous system into the various cranial and spinal nerves to reach distant parts of the body. A nerve fiber in a large animal, such as a horse, may have a length of 4 or 5 feet, and one going to a remote part of a man's body, say to the sole of the foot, is 3 feet or more in length. Other fibers are no more than a fraction of an inch long. Upon a rough calculation it may be said that if it were possible to join all the fibers in the nervous system end to end they would form a thread which could be wound many times around the earth at the equator. It should again be impressed upon the reader that the fibers (both axons and dendrons) composing the various nerves of the body are processes of nerve cells whose bodies lie in the brain, spinal cord, or spinal ganglia (p. 269).

Communications between nerve cells are carried out through their processes. The terminals of an axon of one nerve cell make contact with the dendron or dendrons of another, or with the surface of the other cell body. An axon never makes contact with another

axon; and a dendron never connects with the dendron of another nerve cell. In the central nervous system several nerve cells, and often great numbers, are connected together in this way to form long "nerve chains." It will be noticed that in Figure 30.1 the two nerve cells do not join. Their branches merely touch, like the branches of two trees growing side by side. This relation of the two processes to each other is called a *synapse*. The nerve impulse travels from one process to the other across this union.[1] Most of

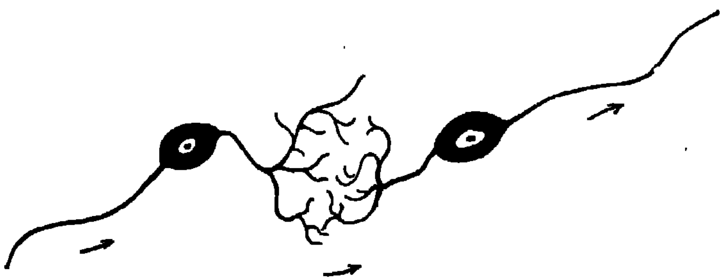


FIG. 30.1. Illustrating a communication between two nerve cells—axon to dendron (synapse). The arrows indicate the course taken by the nerve impulse.

the nerve cells in the brain and cord are connected with all the other nerve cells, and so any one nerve cell can send impulses to almost any other cell of the central nervous system. All these communications, of course, cannot be direct ones. That would be an utter impossibility. Since there are 12 billion cells, each cell, in order to send impulses to and receive impulses from every other cell, would need to have 24 billion fibers. The difficulty is overcome by having the impulses from large numbers of cells brought to central exchanges or stations, which are composed of smaller groups of nerve cells connected together. These central stations are connected with other stations, which in turn are connected with and receive impulses from many other nerve cell groups.

We have all experienced the long train of thought which may be started in our minds by perhaps some very trivial thing—the sight of a familiar object, the smell of some well-known flower, or

[1] It is more likely that a fresh impulse is created at the junction rather than that the impulse passes from one neuron to the other across the synapse.

the sound of some old tune. A number (perhaps comparatively small) of nerve cells have been excited by the sight, smell, or sound. They send impulses with lightning speed to vast hosts of other cells to create the pictures and thoughts in our minds. As these words are being written, some nerve cells are awakened at the seat of memory in the writer's brain. Others are being excited through the eyes as he sees the words he has written; still more are directing the movements of his fingers as he writes, while others are forming

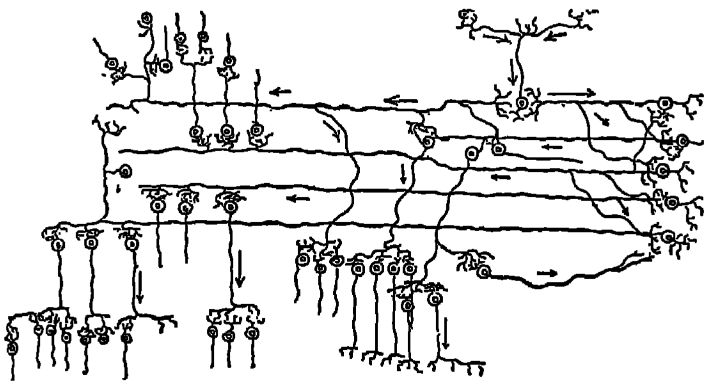


FIG. 30.2. Diagram to show how a few nerve cells may communicate with a great number of others in different parts of the central nervous system.

the thoughts and ideas which he endeavors to put upon the paper. Other cells are receiving impulses through the nerves of hearing and the nerves of touch. All these myriads of cells are linked into a communicating system of the utmost intricacy. The cells in the central "exchanges" never give the "wrong number"—that is, discharge impulses over the wrong fiber. Not only must nerve impulses be transmitted along the right path, but they must be very accurately timed. They must not be even a thousandth of a second early or late in arriving at their destination. All must be dispatched in perfectly regular order. Sometimes, though seldom, a mistake in timing is made. While eating, for example, the tongue may be bitten. This unpleasant experience results from the messages to the tongue arriving a little too late or the messages to the jaw muscles arriving too early, so that the tongue does not get out of the way of the teeth quickly enough. Again, food sometimes "goes the wrong way";

that is, a little food slips into the larynx at the upper end of the windpipe (trachea), and we cough and splutter. The messages from the brain which should close the entrance to the larynx when we swallow have not arrived on time, and the food has passed into the forbidden region (p. 215).

Reflex Action

Anyone who has fished with worms for bait knows how the worm twists and coils as though in agony when the hook transfixes it. Very tender-hearted persons are inclined to pity the squirming worm, and in their minds compare it with some higher animal and think the movements mean that the creature is suffering. But the worm has no brain; therefore it cannot feel in the sense that a horse or a dog or a human being feels. The antics of the transfixed worm are performed unconsciously and are a form of reflex action. Merely touching or pricking the worm will produce the coiling and twisting motions which seem expressive of resentment—for even a "worm will turn." Also, when a person accidentally touches a hot object which causes pain, or pricks a finger, he quickly draws the injured part away (Plate V*a*). As we know, this is a purely involuntary movement, and, though we feel pain at the time, this sensation is not absolutely necessary for the action to occur. For example, a frog with its brain destroyed will quickly pull its foot away when touched with something hot. Even if the toes are pinched, it will withdraw its foot. Obviously, the animal cannot feel in the ordinary sense of the word. These are all examples of reflex action.

Reflex action (also simply called a reflex) is an automatic, involuntary, and often unconscious act, brought about when certain nerves are stimulated. Of all the duties or functions performed by nervous tissue, reflex action is the most elementary. The movements of such simple animals as jellyfish, clams, worms, snails, etc., are purely reflex in nature. Many of our everyday acts, also, are simply reflexes. The winking of the eye when a particle of dust touches an eyelid; coughing when some material finds its way into the larynx; sneezing when something irritates the inside of the nose; the quick recovery of the body's balance when we trip and nearly fall; the pulling away of the hand or other member when it is

hurt, are all examples of reflexes. These actions occur apart from our wills or intelligence. Nevertheless we can often, through the exercise of higher faculties, to some extent control them. Some people have greater control than others. Children usually have less control than older persons. For instance, when one is in the dentist's chair and is suddenly hurt, the first impulse is to jump or jerk the head away, but one manages, through the exercise of his will power or, as it is often called, his self-control, to prevent the reflex from coming into effect.

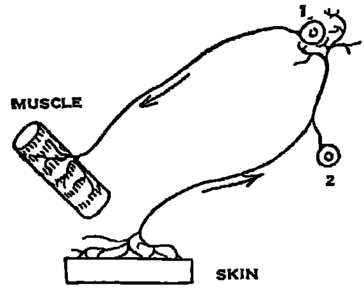


FIG. 30.3. Diagram of a reflex arc, showing a connection between two nerve cells.

A sudden, intense pain may start a reflex which comes into action so quickly that it is impossible to check it. A motorist, for example, driving along the highway in the summer, is sometimes stung by an insect. The acute pain causes a reflex movement of the hands and body to occur so suddenly that it cannot be checked. The control of the car for an instant may be lost, and a serious accident may occur. Besides such obvious reflex actions as those just mentioned and of which we are conscious, a very great many of the functions of our bodies are carried out reflexly but unconsciously. The action of the heart, the secretion of saliva and of gastric juice, swallowing, the movements of the stomach and intestines, as well as many other vital actions, are quite automatic, unconscious, and involuntary. Most of these are carried out through the autonomic nervous system (p. 313).

How the stimulation of a nerve causes a reflex.—It was mentioned on page 269 that a nerve cell has two fibers or processes. One of these, the dendron, carries impulses to the nerve cell; the other, the axon, carries impulses from the cell body. At least two nerve cells are necessary for a reflex. The axon of one cell (1) is brought into contact with the body or the dendron of the other (2), as

shown in Figure 30.3. The dendron of cell 2 is simply one of the fibers of a sensory nerve. It is a nerve, let us say, which goes to the skin and ends in a receptor. The axon of cell 1 goes to a muscle. When, therefore, the ending of the sensory nerve is stimulated—as when the skin is pricked or burned—a message passes in the direction of the arrows to the central nervous system and then to the muscle. In other words, the message is turned back or *reflected* to a point near the one from which it started, hence the name reflex. Now we may see how the hand almost inevitably must be jerked away when the finger is hurt.

FIG. 30.4. The ending of a motor nerve in a muscle fiber.

Reflexes may be carried out through the nerves of the brain (cerebral reflexes), as in the winking reflex; or they may occur through the spinal nerves (spinal reflexes), as when the finger is burned or pricked. Figure 30.3 may be taken to represent two nerve cells in a spinal reflex. Of the two cells, the body of No. 1 lies within the cord itself. The body of the other, No. 2, lies close to but not actually in the cord. So, we may represent these two nerves lying in their proper positions as in Plate V*b*.

Figure 30.3 shows the simplest possible kind of reflex. There are only two nerve cells. Probably no reflex in the human body involves only two cells. Though the general principle is the same as when the message is carried by only two cells, usually hundreds or even thousands of cells transmit messages when a reflex act occurs. For example, many fine nerves end in a very small area of skin, and many motor nerve branches go to even the smallest muscle. Indeed, every single muscle fiber receives a nerve fiber (Fig. 30.4). So, then, when the arm muscles suddenly draw the hand away as a result of some painful stimulation of the skin, messages travel along many sensory fibers and are reflected along a very great number of motor nerve fibers to the various muscles of the arm. The nerve cells which furnish the dendrons to skin and the axons to muscle may also communicate with many other cells within the central nervous system, and so during the performance of a complicated reflex act enormous numbers of nerve cells may be involved.

Definitions of terms.—The complete pathway along which an impulse passes to produce a reflex act—that is, from skin to spinal cord, for example, and from cord to muscle—is called the *reflex arc*. The ingoing "leg" of the journey is called the *afferent limb* of the arc; the outgoing—that is, from cord or brain to muscle (or gland) —is called the *efferent limb*. In Plate V*b* is depicted a reflex arc composed of three nerve cells; one lies entirely within the cord and connects the fibers of the other two. Practically all reflexes of man and higher animals involve these three types of nerve cells. The one carrying the impulse to the central nervous system is frequently referred to as the *receptor neuron*, and the one leading from cord to muscle (or gland) as the *effector neuron*. The connecting link within the cord is called the *connector neuron*.

Reciprocal Action of the Muscles

When the forearm is moved, as, for example, when the hand is raised to the face, the muscle on the front of the arm (the *biceps*) shortens (contracts) and pulls upon the forearm to bend the elbow. When the arm is straightened again, a muscle (*triceps*) on the back of the arm contracts and pulls upon the forearm to bring it into a straight line with the upper arm. It must be quite clear that both muscles, biceps and triceps, should not shorten at the same time. One must lengthen (relax) when the other contracts. Otherwise, the two muscles would pull against each other, and the arm could not be bent, or, if it had been bent, it could not be straightened. No matter how quickly a person bends and straightens his arms, as in boxing or rowing, or bends and straightens his legs, as in running or jumping, the muscles on the fronts and backs of the limbs nearly always act in the proper way—one set contracting, the other set relaxing. Sometimes, however, one set of muscles does not relax as it should, and the arm or leg cannot be bent should it be straight, or straightened should it be bent. The limb is held set and fixed. This is what happens when a person "takes cramps." When the muscles are acting in the normal way, messages are arriving at one instant in one set of muscles telling them to contract, while messages are ordering the opposite muscles to relax. At the next instant the messages are reversed, the group of muscles which were contracting are told to relax, and those which were relaxing

are now told to contract. The messages must be timed with an accuracy measured by small fractions of a second. This give-and-take, this "seesaw" of contraction and relaxation, brought about by the accurate timing of the messages arriving along the nerves to the muscles, is called *reciprocal action* [2] (Fig. 30.5).

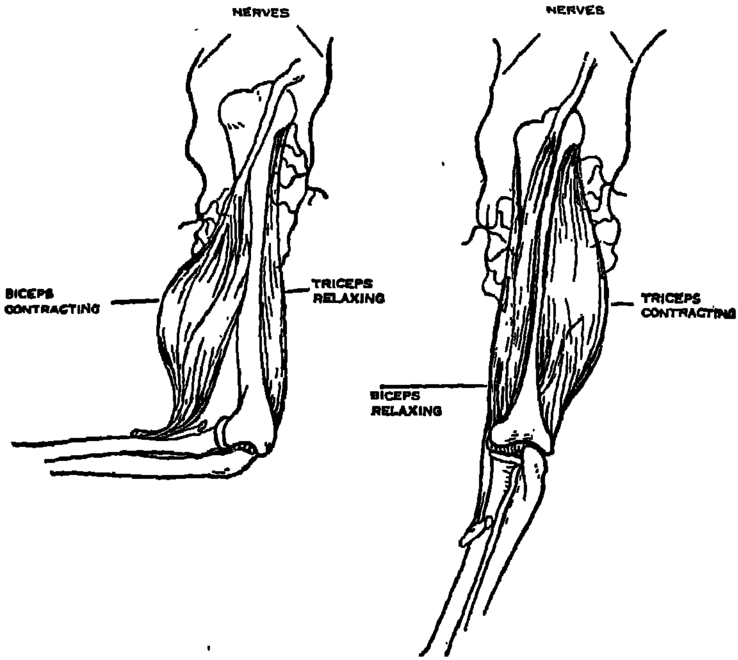


FIG. 30.5. Reciprocal innervation.

In the body, a great number of muscles of various sizes and shapes act in a regular and orderly way to bring about muscular acts. Each muscle, in turn, is made up of an immense number of separate fibers (p. 23), and each fiber must receive a separate message or command from the central nervous system before it will relax or contract.

In order to realize with what wonderful precision the human machine of brain, nerves, and muscles does its work, one needs

[2] The arrangement of nerves whereby the messages (of contraction or relaxation) are conveyed to the alternating muscles (e.g., biceps and triceps) is termed *reciprocal innervation.*

only to think of a pianist reading and playing a difficult piece of music. The musician's brain is interpreting the notes of the music, which he sees through messages received from the eyes. Messages are sent racing at a speed of 400 feet per second along the trunk lines and innumerable "wires" of his nervous system. The muscles of the shoulders, arms, wrists, and forearms are contracting and relaxing with the precision of a complex machine. His fingers are twinkling over the keyboard; each small muscle pulls upon the finger bones at the right instant and relaxes the next to allow another muscle to contract. A similar give-and-take is seen in other muscles of the body. In speaking, for instance, muscles of the tongue, lips, cheeks, throat, and chest all act with one accord. No muscle interferes with the action of another

chapter 31

THE SPINAL CORD AND NERVE TRUNKS

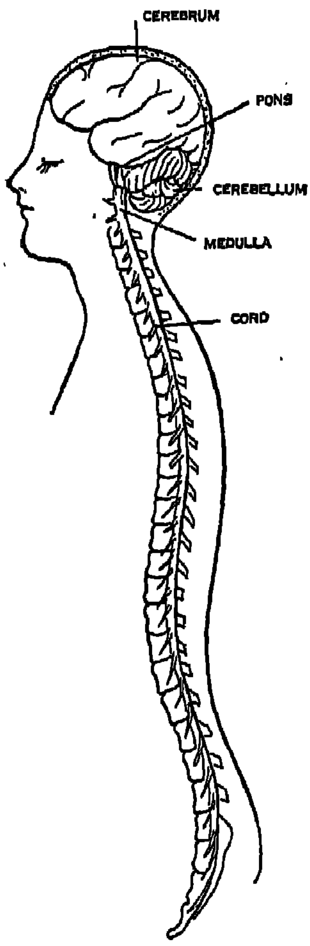


FIG. 31.1. Outline sketch of the central nervous system.

The nervous system consists of (1) the spinal cord, (2) the nerve trunks and (3) the brain. The brain and cord together are called the *central nervous system* (Fig. 31.1).

THE SPINAL CORD

The spinal cord is white and soft like marrow and about ½ inch in diameter. It lies within the arches of the vertebrae, which form a bony tunnel to protect it from shocks and other mechanical injuries. Many nerves leave and enter the cord and serve to carry impulses between the various parts of the body and the central nervous system (Fig. 31.2). When the spinal cord is sliced through transversely, it is found that its center or core has a darker color than its peripheral portion (Fig. 31.6). This central part, which has a shape resembling that of a butterfly, is, like the cortex of the cerebrum, composed of *gray matter* (nerve cell bodies). The wings of gray matter

are inclined forward and backward. The former are broad and called the *anterior* (or *ventral*) *horns;* the more slender hind parts of the wings are called the *posterior* (or *dorsal*) *horns.* The nerve cells of the anterior horns give rise to fibers (axons) which leave the cord by the anterior roots of the spinal nerves (p. 292). The cells of the posterior horns receive fibers from the posterior roots. The part of the cord surrounding the central gray area is composed entirely of *white matter*—that is, bundles of nerve fibers. The spinal cord is ensheathed by three membranes—*dura mater, arachnoid,* and *pia mater*—which are continuous with those of the same names covering the brain (p. 294). Cerebrospinal fluid also fills the space between the arachnoid and the pia mater.

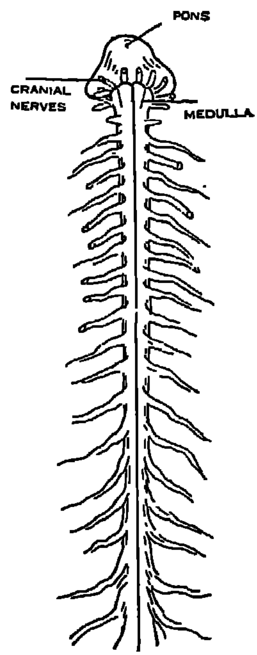


FIG. 31.2. The spinal cord with its nerve roots. The lower ten pairs of nerve roots which come off from the lower part of the cord are not shown.

As well as being a *reflex center* (p. 282), the spinal cord is a two-way *conducting pathway.* Its fibers transmit motor impulses from the motor area of the brain (p. 302) to the cells of the anterior horns; sensory and other impulses which it receives through the posterior roots are conveyed in the opposite direction.

The white matter of each half of the cord is divided into three columns—*anterior, lateral,* and *posterior*—by the gray matter of the anterior and posterior horns and the emergence of the roots of the spinal nerves (Fig. 31.3). The fibers of these columns are gathered into groups called *tracts* in accordance with their origins and destinations. Those which transmit impulses upward are called *ascending tracts;* those which carry impulses in the reverse direction are called *descending tracts.* The tracts of the posterior columns transmit to consciousness impulses of touch and of pressure received through the posterior roots. The lateral columns carry non-sensory impulses from the muscles and joints to the cerebellum (*cerebellar tracts*). These columns also conduct pain impulses

and impulses in the opposite direction from the motor area of the brain to cells in the anterior horns. The latter impulses ultimately reach the skeletal muscles through the various motor nerves. This tract is called the *corticospinal.*

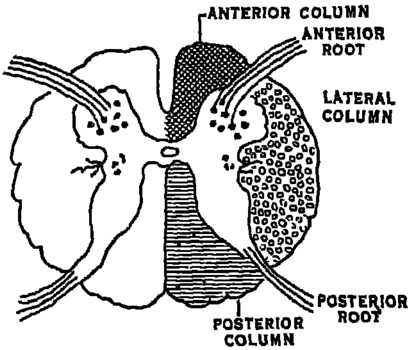


Fig. 31.3. Diagram showing the cross section of the spinal cord and the fibers leaving and entering by the anterior and the posterior nerve roots. The left half of the cord is left blank; on the right side the three main columns of the cord are shown in cross section being marked by distinctive shading. The small dots in the anterior horns represent the anterior horn cells.

The Nerve Trunks

The nerves are long, tough cords which connect the muscles, skin, sense organs, and practically every tissue of the body with the spinal cord and brain. Each nerve is simply a great number of nerve fibers, bound together side by side like fine wires in an electric cable. If one takes a piece of ordinary electric extension cord and cuts off the cloth cover, a rubber insulating material will be found underneath. When the rubber is removed, a large number of fine copper wires are seen within, bound closely together. A nerve is made up in somewhat the same way. The nerve is covered on the outside by an insulation of fatty material. Within this are a great number of fine fibers, and in ordinary nerves each fiber is insulated from its neighbor. But the nerve fibers are also very much finer and a great deal more numerous than the fine copper wires in the electric cord. They are too fine to be seen with the naked eye, and a large nerve may contain many thousands of them (Fig. 31.4). *Each fiber is a process of a nerve cell of the central nervous*

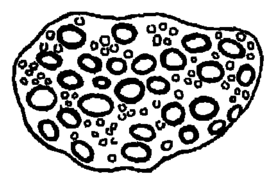


Fig. 31.4. A cross section of a mixed nerve. The very fine circles are sympathetic nerve fibers (p. 313).

system (p. 269). Some nerves have only ingoing fibers—that is, fibers which carry impulses (p. 271) to the central nervous system. Nerves which carry ingoing impulses are called *afferent nerves.* Afferent nerves may carry conscious impulses; it is the information carried by these nerves which enables us to see, hear, smell, taste, and feel. Such afferent nerves are therefore also called *sensory*

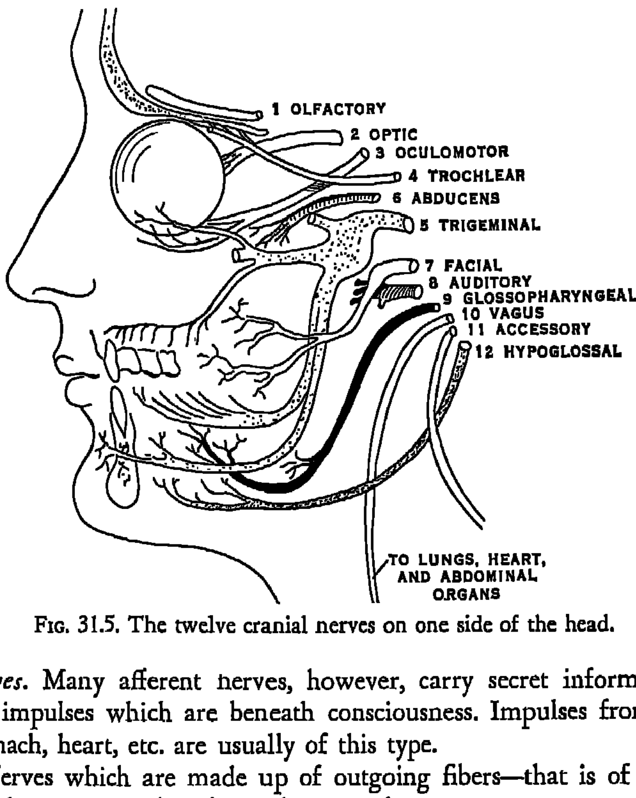


Fig. 31.5. The twelve cranial nerves on one side of the head.

nerves. Many afferent nerves, however, carry secret information, i.e., impulses which are beneath consciousness. Impulses from the stomach, heart, etc. are usually of this type.

Nerves which are made up of outgoing fibers—that is of fibers which carry impulses from the central nervous system, are called *efferent nerves.* These nerves carry impulses which cause the movement of muscles or the secretion of glands. They are therefore also called *motor nerves* or *secretory nerves.*

A nerve, like a telephone cable, may, however, be made up of two kinds of fibers, one set carrying impulses to the central nervous system (afferent fibers) and the other set carrying impulses away (efferent fibers). A nerve of this type is called a *mixed nerve.*

Nerves also are given names to indicate their origins. For instance, the afferent nerves of sight, hearing, smell, and taste, the nerves of the teeth and of the skin of the face, and the motor nerves (efferent) to the facial muscles, since their fibers pass directly to or from the brain and therefore enter or issue from the cranial cavity, are all called *cranial nerves.* There are 12 pairs of cranial nerves, all of which except the first two spring from the brain stem (p. 306) and are numbered in order from above downward, 3 to 12. The first and second pairs (olfactory and optic) are the nerves of smell

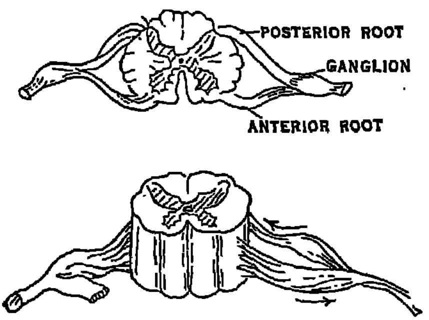


FIG. 31.6. The spinal nerve roots of one segment of the cord. The arrows in the lower figure indicate the directions taken by the nerve impulses.

and sight; they are joined to higher parts of the brain (see Fig. 31.5).

The nerves which enter (afferent) or leave (efferent) the cord are called *spinal nerves.* There are 31 pairs of these (Fig. 31.2). When the spinal canal, formed by the vertebrae, is opened up, the nerves can be seen leaving the cord throughout nearly its entire length. The nerves leave the spinal canal by passing between the bodies of the vertebrae. Each spinal nerve has an *anterior* and a *posterior root,* which emerge in vertical series from the longitudinal grooves between the columns of the cord (Fig. 31.6). The anterior roots are composed entirely of efferent fibers, most of which are motor; they enter into the formation of one or other of the various nerves and relay impulses received by the anterior horn cells via the corticospinal tracts to the voluntary muscles. Fibers of the autonomic nervous system (p. 313) also leave the cord by the anterior roots. The posterior roots contain only afferent fibers, many of which are sensory, but others of which carry impulses which are destined for the cerebellum and other parts of the brain concerned with subconscious functions. The two spinal nerve roots join a short

distance from the cord to form the complete nerve trunk, which, being composed of both afferent and efferent fibers, is therefore a *mixed nerve*. But at variable distances along their course from the cord to their destination, motor, sensory, and autonomic fibers become separated from one another to form smaller nerves composed purely of one or the other type. The individual fibers of these finally separate, like the strands of a frayed rope, to end in muscle, skin, gland, etc.

A small swelling is seen on the posterior root of each spinal nerve. This enlargement, called a *ganglion*, is made up of a mass of nerve cells. It is these cells which supply the afferent or sensory fibers of the mixed nerve (Fig. 31.6).

Should a sensory nerve be cut or destroyed by disease, no impulses can reach the brain from the organ, whether eye, ear, or skin, in which this nerve had its ending. Blindness, deafness, or loss of sensation in the skin, according to the nerve injured, would be the consequence. When a motor nerve is cut through or seriously injured, no impulses can reach the muscle in which the nerve ends; so the muscle cannot be made to contract—it is paralyzed.

chapter 32

THE BRAIN

The brain is a soft mass of nervous tissue weighing about three pounds. It is irregularly egg-shaped. Its undersurface is somewhat flattened and rests upon the floor of the skull. Its upper surface is curved into an oval dome and lies just beneath the roof of the skull. The under, flattened part of the brain is called the *base* and the rounded upper surface the *vertex.* The brain and spinal cord are enclosed within three membranes laid one inside the other and called *meninges* (Fig. 32.1). The outermost membrane, which is the toughest and thickest of the three, is called the *dura mater.* The middle and more delicate membrane is known as the *arachnoid.* Between these two membranes is a slight space containing fluid and known as the *subdural space.* The third and innermost membrane is closely attached to the surface of the brain. It carries the fine blood vessels and is called the *pia mater.* Between the arachnoid and the pia mater is a much larger space called the *subarachnoid space.* It is continued downwards between the arachnoid and pia mater of the spinal cord, and contains a considerable body of a thin liquid known as the *cerebrospinal fluid.* Inflammation of the brain membranes is called *meningitis.*

There is probably no organ in the body which shows such great differences in shape, weight, size, and degree of development in various animals as does the brain. The brain of a rabbit or of a rat, or even of a cat or a dog, resembles the brain of a man only in a very general way. The brains of these animals, which also, of course, are not nearly so large as the human brain, are poorly developed. The front part is flat or sloping and narrow, not high and filled out like the brain of man. The vertex also in lower

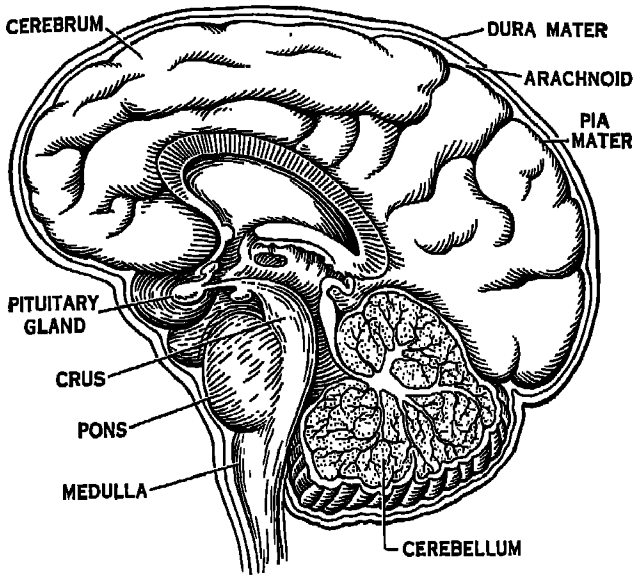


FIG. 32.1. The brain divided by a vertical section between the cerebral hemispheres. The brain stem includes the crura (sing. crus) or cerebral peduncles, pons, and medulla oblongata.

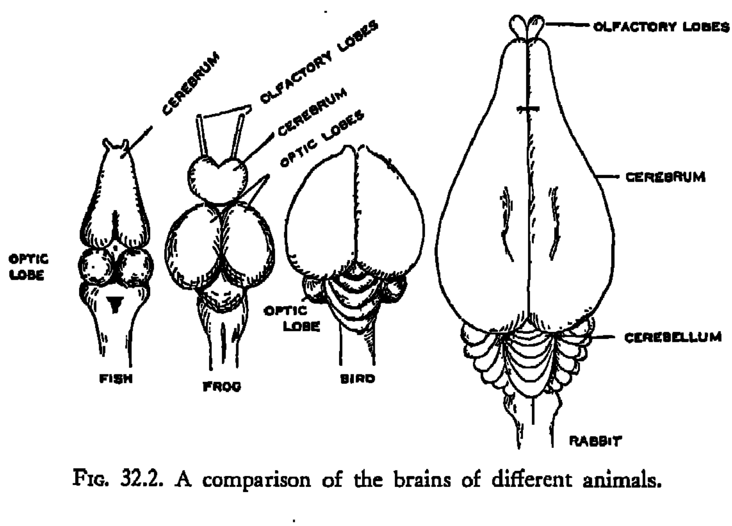


FIG. 32.2. A comparison of the brains of different animals.

animals is much flatter and does not rise in the rounded swelling so characteristic of the human brain. In animals still lower in the scale, such as fish, snakes, and frogs, the brain is by comparison a very simple affair. The parts which have to do with the sense of smell (olfactory lobes) and of sight (optic lobes) form a large part of these primitive brains. In man the olfactory lobes are of an almost insignificant size. No definite optic lobes are seen, and the great

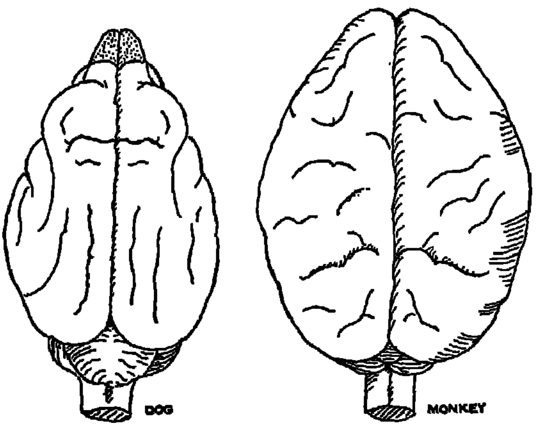


FIG. 32.3. Brains of a dog and a monkey. Compare the monkey's brain with the human brain.

development of that part of the brain concerned with the higher faculties (the *cerebrum*) completely overshadows those primitive parts so prominent in the brains of the lower animals (Figs. 32.2 and 32.3).

Though all that part of the nervous system lying within the skull is spoken of in general terms as the brain, differences in size, shape, and function of different portions of the whole enable it to be divided for convenience of description into three chief masses. These are the *cerebrum,* the *brain stem,* and the *cerebellum;* each will be described separately (see Figs. 32.4 and 32.18).

THE CEREBRUM

The cerebrum is the dome-shaped mass of brain substance which lies just beneath the skull roof and fills the greater part of the cranial cavity. It weighs nearly two pounds. It is this part which makes the human brain so different both in appearance and in

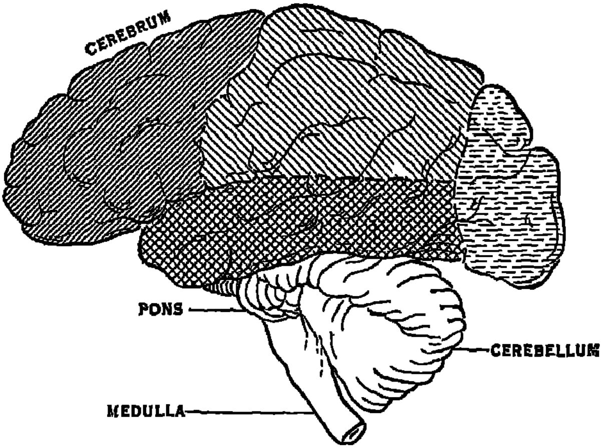


FIG. 32.4. The human brain; cerebral lobes marked by different shading.

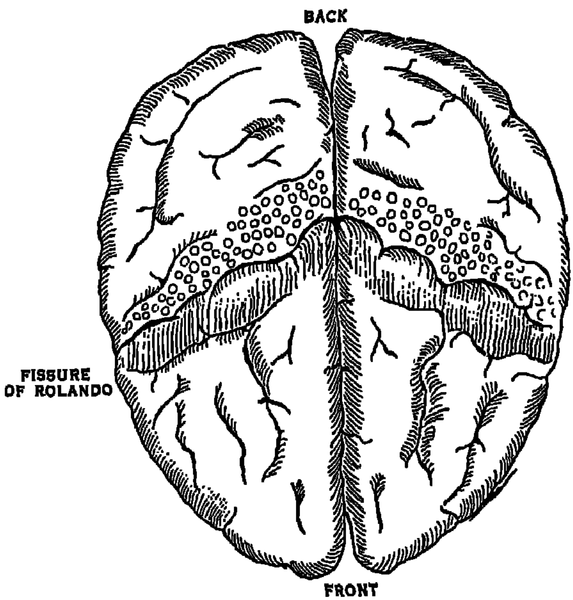


FIG. 32.5. The human brain from above. A longitudinal fissure divides the cerebrum into two hemispheres, each of which is marked off near its center, but not divided, by the fissure of Rolando. The shaded area in front of this is the motor area. The band behind marked by small circles is the somesthetic area. The fissure of Rolando separates the frontal from the parietal lobe.

capability from the brains of animals. The general form and structure of the human cerebrum reminds one of the kernel of a walnut. The kernel of the walnut is protected by a shell, just as the brain is protected by the skull bone. The walnut's kernel is divided lengthwise into two halves; so also is the cerebrum, each half of which is called a *cerebral hemisphere.* The surface of the nut's kernel is covered with many wrinkles—little hillocks and furrows. The surface of the cerebral hemispheres is wrinkled or grooved in

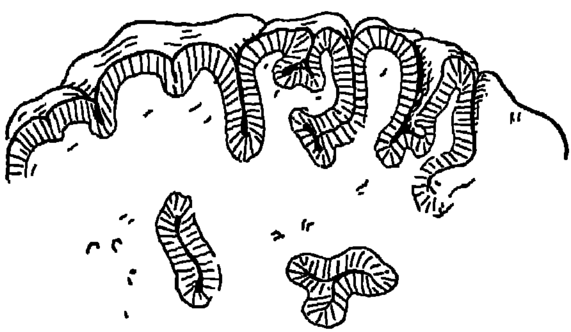


Fig. 32.6. A vertical section through the cortex to show how the gray matter dips into the white matter around the fissures and sulci. This indicates that the convolutions have been formed by an infolding process.

an irregular and somewhat similar way. The wrinkles and furrows upon the surface of the brain are very important and are called *convolutions* (Fig. 32.5 and 32.6). The groove between two mounds, if small and shallow, is called a *sulcus* (plural, *sulci*). If the groove is long and deep, it is called a *fissure.* Were we to slice the kernel of the walnut with a sharp knife, we should find that the cut surface was a creamy color through and through. But if we were to slice one of the cerebral hemispheres in the same way, the cut surface would be found to have a pale grayish or brownish color near the outside of the brain and a lighter creamy color toward the center. The darker material on the surface of the hemisphere is called *gray matter.* It contains great numbers of nerve cells. The creamy colored material in the center is called *white matter.* It is made up of countless numbers of nerve fibers. The gray matter covering the surfaces of the hemispheres is called the *cerebral cortex* (L. *cortex* = bark or rind) (Figs. 32.6 and 32.7). The hemispheres are joined

together by a tough mass of fibers called the *corpus callosum* (Fig. 32.8).

The gray matter dips into and lines the floor and walls of the fissures and sulci. Thus, there is an obvious purpose in the convolutions of the cerebral surface. They allow for an increase of cortical

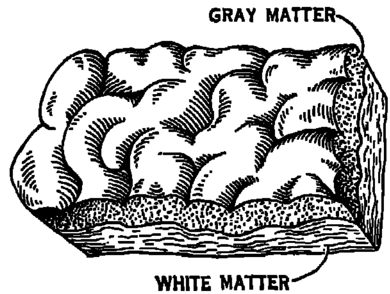


FIG. 32.7. A section of the superficial part of the cerebrum to show the gray matter of the cortex and the underlying white matter.

substance (gray matter) with a minimum increase of cerebral size. The amount of gray matter of the highly convoluted human cerebrum is immensely greater than that of the brains of subhuman species without there being a proportional increase in skull capacity.

By means of the fissures which mark out its surface, each cerebral hemisphere may be divided into four masses called *lobes*. Two

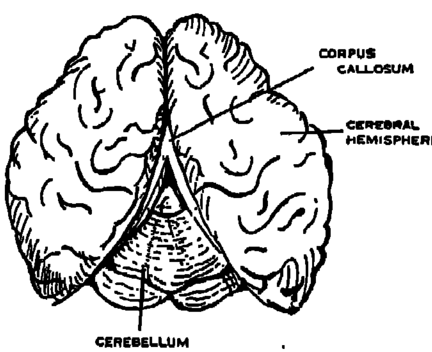


FIG. 32.8. The hemispheres have been spread apart to show the connecting mass of white matter—*corpus callosum*—which is also partially divided lengthwise to show the cerebellum.

main fissures will be seen in the diagram of the brain shown in Figure 32.9. One of these fissures slants downward and forward from the top and near the center of the hemisphere. It is called the *fissure of Rolando*. The part of the hemisphere lying in front of it is called the *frontal lobe*, and the part of the brain lying behind it

is known as the *parietal lobe*. At the lower part of the hemisphere a rounded shoulder of the cerebrum will be seen. This is the *temporal lobe*. The deep fissure which separates it from the parietal and frontal lobes above is called the *fissure of Sylvius*. The triangular region lying behind the parietal and temporal lobes is called the *occipital lobe* (Figs. 32.4 and 32.5).

The functions of the cerebrum.—The cerebrum is undoubtedly the seat of the mind; it is the organ of thought. Intelligence, memory, reason, and all those mental endowments in which man excels so greatly the rest of animal creation are held within the cerebrum. Consciousness depends upon the activity of the nerve cells massed together mainly in the cerebral cortex. It is because we have a cerebrum that we know that we live. Animals upon the lower rungs of life's ladder, such as worms and snails, which have no central nervous system, and even fish and frogs, which have a very elementary cerebrum, cannot be said to possess a consciousness. They are really little more than machines, in which nerve cells and fibers, muscles and reflex action take the place of batteries, wires, pistons, and wheels. Should the cells in the cortex of the human cerebrum be injured, as by a blow upon the head, or should they be temporarily numbed, as by an anesthetic (ether, chloroform, alcohol, morphine), unconsciousness results. If the cerebrum is removed from such animals as fish and frogs, though they show little inclina-

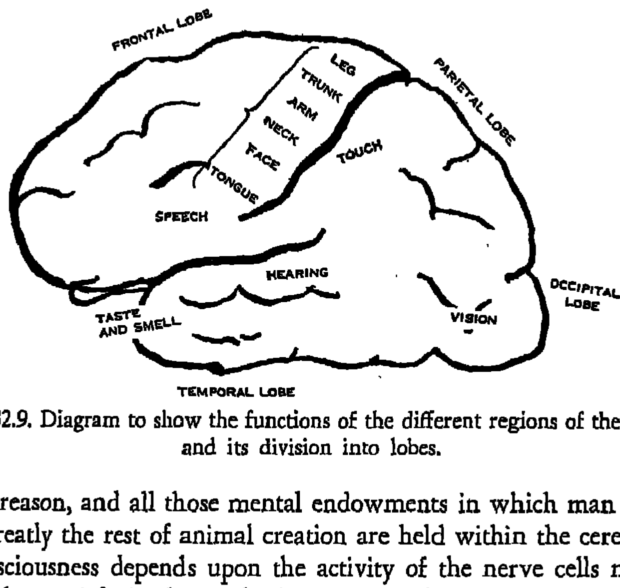


FIG. 32.9. Diagram to show the functions of the different regions of the cortex and its division into lobes.

tion to move about, they will snap at food and otherwise appear quite normal. But the cerebrum in such creatures, as compared with that of intelligent animals such as dogs, is not of much importance. Even a dog, however, may have its cerebrum removed, and, though the animal is without memory and shows no intelligence, it can feed itself and moves about when disturbed. It sleeps most

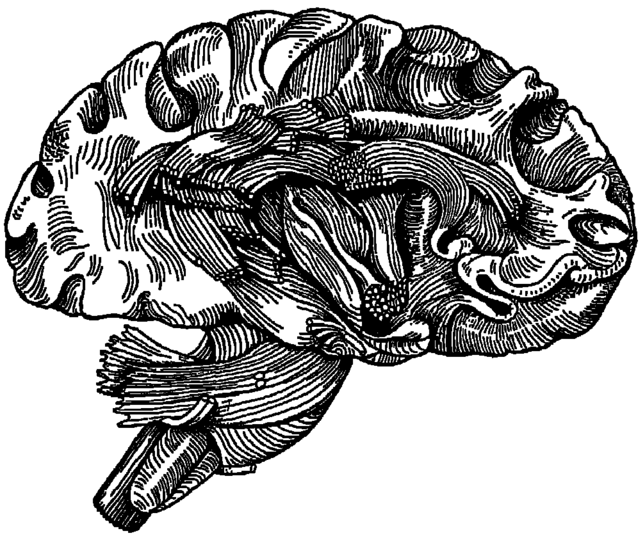


FIG. 32.10. Dissection of the interior of a cerebral hemisphere, showing bundles of nerve fibers. (*Redrawn from Gray's Anatomy.*)

of the time and is roused with difficulty. It is simply a machine, motivated and guided by reflex action. Man, of course, could not live for any time without a cerebrum; nor probably could monkeys or apes.

It has been thought that mental processes were carried on mainly in the cortex of the frontal lobes. But modern experiments upon higher animals—e.g., monkeys and apes—and observations upon human subjects who have had the frontal lobes severely damaged by accident or removed by operation have required a revision of this belief. A man deprived of his frontal lobes, though upon a close examination he will show some mental and moral defects, may appear quite normal to a casual observer and be able to perform ordinary mental tasks. No region of the cerebral cortex can

be singled out as being especially concerned with intellect. If we think for a moment it will be evident why this should be so. Our intelligence has been developed as a result of the manifold and various impressions received from the world around us. Our various experiences are imprinted as memory pictures in various parts of the cerebral cortex, where the impulses received through the sensory nerves—sight, hearing, touch, etc.—are interpreted. These several areas are connected with one another by great numbers of nerve fibers running in the white substance beneath the gray matter of the cortex (Fig. 32.10). These are called *association fibers* or *tracts*. Intellectual capacity is determined by the sum of all those past experiences which can be recalled in consciousness and by the abundance of the association fibers through which the different sensory areas are in communication with one another. Destruction of any one area of the cortex, therefore, may reduce but will not destroy the intellect.

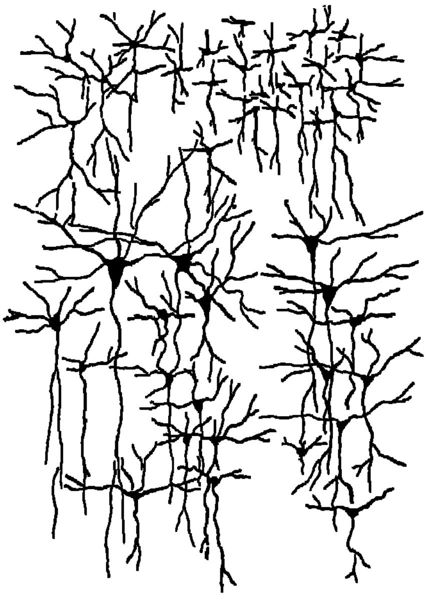


FIG. 32.11. A section of the motor area of the cerebral cortex, showing the large pyramidal cells.

In the frontal lobe is the center for *voluntary muscular movement*. At the hind part of this lobe and just in front of the deep slanting groove known as the fissure of Rolando is a band of cortex containing large pyramid-shaped cells (Fig. 32.11). This cortical region is called the *motor area* or *motor* center (Figs. 32.5 and 32.9). In the cells of this area our wishes are turned into actions. In other words, messages are formed in this area of the cortex which are dispatched along the long fibers of its nerve cells to the various muscles of the body. The cells near the upper part of this band

send fibers to the muscles of the toes; the cells toward its lower end send fibers to the muscles of the face. The rest of the area sends "orders" to the muscles of the ankle, leg, knee, hip, trunk, shoulder, arm, hand, neck, face, mouth, and throat in this order from above downward. The center for speech lies close to the area which governs the muscles of the face and throat. The center for writing lies near the center for the muscles of the hand.

The identification of the parts of the motor area governing the various muscle groups was first shown by experiments upon animals, especially apes and monkeys, whose brains are most like the human brain. When the motor area of an ape's brain is exposed under an anesthetic and its different parts stimulated successively with a weak electric current, the muscles governed by the nerve cells in the stimulated part contract. Thus, flexion or extension of a limb can be readily induced. Similar observations have been made on man during operations upon the brain. In this way the motor area of the human cerebral cortex has been accurately mapped out. Sometimes an injury to the head causes a piece of the skull bone to press upon and irritate some part of this area and cause uncontrolled muscular contractions. The contractions, which at first are usually confined to a small group of muscles—arm, leg, etc.—quickly spread to involve other muscles, until generalized convulsions may be developed. This disease is called *Jacksonian epilepsy*. By observing in which muscles the contractions start the surgeon knows where to look for the irritated nerve cells.

The impulses discharged from the motor area to the muscles pass along two fiber links. The cells of this area, as mentioned above, are very large and have a pyramidal shape, and their axons—the first fiber links—form a bundle of fibers, the *corticospinal* or *pyramidal tract*. These fibers pass downward through the center of each cerebral hemisphere, forming part of its white matter. They continue through the base of the peduncle, pons, and medulla (p. 306). At the lower border of the medulla most of them enter the lateral columns of the spinal cord, but first, before entering the cord, the fibers from one hemisphere cross with those descending from the other half of the brain.[1] In the cord the pyramidal fibers connect at

[1] A small proportion of the pyramidal fibers (*direct pyramidal tract*) do not cross at the lower border of the medulla but descend directly in the anterior columns of the cord.

different levels with the cells of the anterior horns of gray matter. It is the axons of the anterior horn cells which constitute the second link over which the nerve impulses must pass to reach the muscles. The axons of the anterior horn cells, we have already

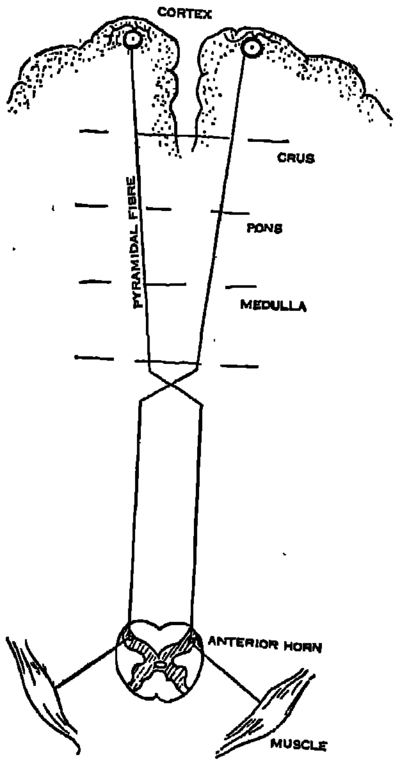


FIG. 32.12. Diagram to show the course of an impulse from the motor area of the cerebral cortex to a voluntary muscle. The horizontal lines indicate the levels of the different parts of the brain stem.

seen (p. 292), leave the spinal cord by the anterior roots of the spinal nerves and are finally distributed to the muscles of the arms, trunk, and lower limbs (see Fig. 32.12).

It is clear that an injury anywhere along the course of the fibers will prevent the message from reaching the muscle, just as surely as a telephone message would fail to be transmitted should the conducting wire be broken. Paralysis of the muscles for which the messages are intended will therefore result, should disease or injury destroy (1) the pyramidal cells in the cortex, (2) the fibers any-

where in their course to the anterior horn cells, (3) the anterior horn cells themselves, or (4) the motor nerves going to the muscles.

An injury to the brain may destroy some of the pyramidal cells in the motor area of the cortex. Apoplexy or *cerebral hemorrhage*

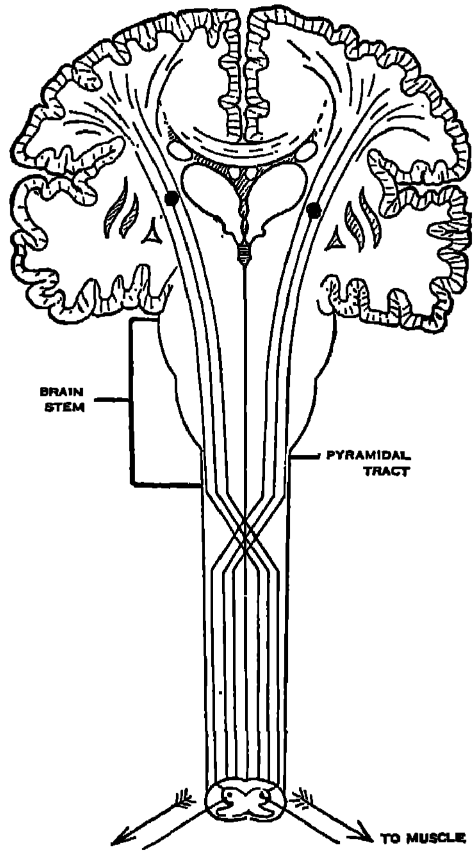


FIG. 32.13. A more detailed drawing than that shown in Figure 32.12 of the course of impulses from the cerebral cortex to a voluntary muscle. The black dots mark the positions where cerebral hemorrhage usually occurs. It is clear that the fibers are massed together at these points in order to pass through narrow channels. Hemorrhage in either of these situations is therefore likely to cause the destruction of a large number of fibers and so produce a widespread paralysis.

is due to the rupture of a small blood vessel in the white matter of the cerebrum, where the pyramidal fibers pass through a narrow gap or "bottleneck" (Fig. 32.13). The escaping blood, therefore, destroys large numbers of fibers and so causes paralysis of one side of the body. Since the pyramidal fibers cross at the lower border of the medulla, the paralysis which results from apoplexy is on the opposite side of the body to that upon which the cerebral hemor-

rhage occurs. In *infantile paralysis* (*poliomyelitis*) some of the anterior horn cells are attacked and destroyed.

In a band of cortex of the parietal lobe lying just behind the fissure of Rolando are recorded the sensations of touch, warmth, and coolness and the senses of position and movement of the different parts of the body. Impulses discharged along the nerves from the various receptors in the skin, muscles, tendons, and joints are received in this area. At the lower end of this region of the parietal lobe, which is called the *somesthetic area,* is the center for the sense of taste.

The cortex of the occipital lobe receives the impulses of sight. The centers for hearing as well as those for smell are situated in the cortex of the temporal lobe.

The main functions of the cerebrum are summarized below.

1. It is the seat of intelligence.

2. In the cortex are centers which govern voluntary movement and record the various sensations.

3. Its interior is composed of a great number of nerve fibers which transmit sensory and motor impulses to and from the cortex.

4. Its interior also contains masses of gray matter which serve as centers for various motor and sensory functions.

The Brain Stem

The cerebrum, like a blossom upon its stalk, appears to spring from a comparatively slender column of nervous tissue called the brain stem. Below, the brain stem becomes continuous with the still slenderer spinal cord. This part of the brain consists of three distinct regions (see Figs. 32.1, 32.13, and 32.18). From above downwards—that is, from cerebrum to spinal cord—they are: the *midbrain* (or *mesencephalon*), the *pons,* and the *medulla oblongata.*

The midbrain or mesencephalon.—The midbrain is the uppermost part of the brain stem, lying just beneath the cerebrum. In man, it is about ¾ inch long. It consists of two parts: (1) the *corpora quadrigemina,* which are four rounded prominences on its posterior or dorsal surface, and (2) the *cerebral peduncles* or *crura.* The cerebral peduncles are composed of two longitudinal columns, known as the *bases of the peduncles* which descend upon the anterior or ventral aspect of the peduncles, and a central mass of nervous

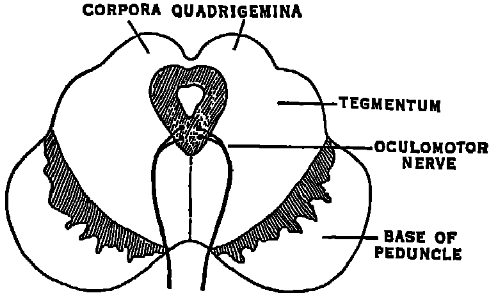


FIG. 32.14. Section through the midbrain (mesencephalon). The serrated mass of gray matter (shaded) between the tegmentum and the base of the peduncle (crus) on each side is the *substantia nigra*. The *red nuclei* are not shown in the figure; they are two rounded masses of gray matter lying in the tegmentum one on each side of the mid-line. The fibers of the oculomotor nerve pass through them. The small triangular area surrounded by gray matter and lying near the dorsal part of the midbrain is the cross section of a short canal—the *cerebral aqueduct*—through which cerebrospinal fluid circulates.

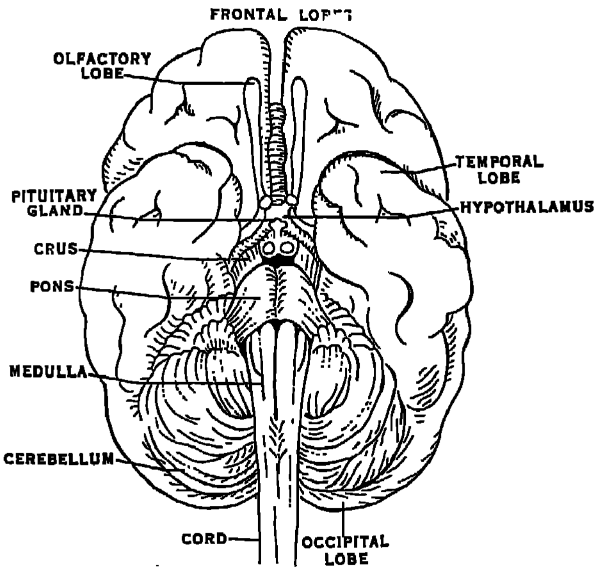


FIG. 32.15. A view of the underside (base) of the human brain. With the exception of the olfactory nerve the cranial nerves have been omitted.

tissue called the *tegmentum* (see Figs. 32.14 and 32.15). The longitudinal columns are made up of bundles of efferent nerve fibers which carry impulses from the cerebrum to other parts of the brain stem or spinal cord. The tegmentum carries bundles of nerve fibers which transmit sensory and other afferent impulses from the spinal cord, medulla, and pons to the cerebrum. The tegmentum is pierced by a canal—the *cerebral canal* or *aqueduct of Sylvius*—the walls of which are formed of gray matter. Nerve cells within this gray mass give rise to fibers which compose the third cranial nerve (oculomotor). Embedded in the mass of white matter of the tegmentum are other isolated masses of gray matter—namely, the *red nucleus* and the *substantia nigra*.

The pons.—The pons is made up to a large extent of the ascending and descending fibers mentioned above. It also contains bundles of fibers which run transversely and appear partly to surround and clasp the brain stem. Behind, the two open ends of the horseshoe-like clasp plunge into the *cerebellum* or little brain. Some of the cranial nerves (p. 292) arise from the pons.

The medulla oblongata.—The medulla oblongata lies just below the pons and rests upon the floor of the skull. It is continuous, below and just outside the skull, with the spinal cord. This part of the brain also transmits the bundles of ascending and descending fibers mentioned above, and contains as well many groups of nerve cells. The work of the vital organs—the heart, the blood vessels, the lungs, the stomach, and the intestine—is guided and controlled by the gray matter in the medulla. Many of the cranial nerves also arise from this part of the brain.

The Cerebellum, or Little Brain

The cerebellum, which is much smaller than the cerebrum, lies under the shelter of the back part of the latter. The cerebellum is connected to the rest of the brain by three bundles of nerve fibers called *cerebellar peduncles*. It consists of two lateral halves called hemispheres. These are joined together by a central somewhat elongated structure which resembles a worm or caterpillar or the body of a butterfly. It is therefore called the *vermis* (L. *vermis* = worm) (Figs. 32.16 and 32.1).

The surface of the cerebellum is quite different in appearance

from the surface of the cerebrum. The irregular convolutions so typical of the cerebral surface are not seen. Instead, several fairly regular and nearly parallel depressed grooves and ridges are seen. Like the cerebrum, the cerebellum is composed of gray and white matter. A large part of the gray matter is on the surface and is called the *cerebellar cortex.* Masses of gray matter are also found

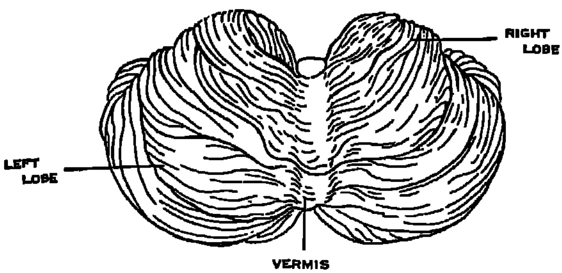


FIG. 32.16. The upper surface of the cerebellum, which has been separated from the rest of the brain.

in its center; the largest of these is called the *dentate nucleus* (Fig. 32.17).

The cerebellar peduncles.—Three pairs of compact bundles of fibers constitute the sole paths of communication between the cerebellum and the rest of the nervous system; these are the *superior, middle,* and *inferior peduncles.* The *superior peduncles* are composed mainly of axons of nerve cells situated in the cerebellum. These fibers connect with nerve cells in the midbrain, from which fibers course upward to the cerebrum and downward to form connections with cells in the pons (*pontine nuclei*), medulla, or spinal cord. These peduncles also carry a smaller number of fibers in the

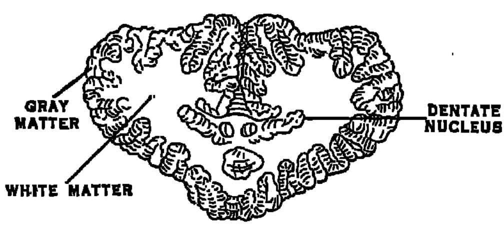


FIG. 32.17. A section through the center of the cerebellum.

opposite direction—i.e., from the spinal cord through the medulla and pons to the cerebellum. The fibers from the spinal cord, like those which travel by the inferior peduncles, convey subconscious impulses from the muscles, tendons, bones, and joints, and thus bring to the cerebellum information concerning the movements and position of the different parts of the body.

The *middle peduncles* unite the cerebellum to the pons. They are composed of those transverse fibers mentioned above which are the axons of cells of the pontine nuclei. These cells are connected in turn with the cerebrum. Thus, through the middle peduncles and pons the cerebrum is in communication with the cerebellum.

The *inferior peduncles* bring the cerebellum into communication with the spinal cord. These peduncles are composed mainly of nerve fibers carrying impulses from the muscles, tendons, bones, and joints. They also contain fibers which carry impulses to the cerebellum from the semicircular canals of the internal ear (p. 385). The complicated connections between the cerebellum and the rest of the nervous system through the three pairs of cerebellar peduncles will be best understood from a study of Figure 32.18.

The functions of the cerebellum.—This part of the brain carries out its very important functions beneath consciousness. Non-sensory impulses are being received ceaselessly by the cerebellum from various parts of the body—the muscles and joints of the limbs, neck, and trunk, the eyes, and the semicircular canals in the internal ear (p. 385). The impulses received from these various parts inform the cerebellum of the positions and movements of the parts. The cerebellum sends messages in turn through the cerebrum and midbrain to the muscles and keeps them in a certain degree of tension or tautness necessary for the execution of muscular acts in a smooth and co-ordinated manner. Precise movements of the fingers or of the limbs, for example, would be impossible in the absence of the cerebellum. In experimental animals deprived of this part of the brain, or in patients suffering from cerebellar damage (tumor or gunshot wound), the movements lack smoothness and precision; trembling and jerkiness of action result. The tension of the muscles necessary for standing or for walking or for holding the limbs firmly and steadily is lost. Normally, messages from the cerebellum

dispatched to the neck muscles keep the head poised at the correct angle, no matter what change is made in the body's position.

The cerebellar peduncles are the means whereby the cerebellum communicates with the rest of the central nervous system and

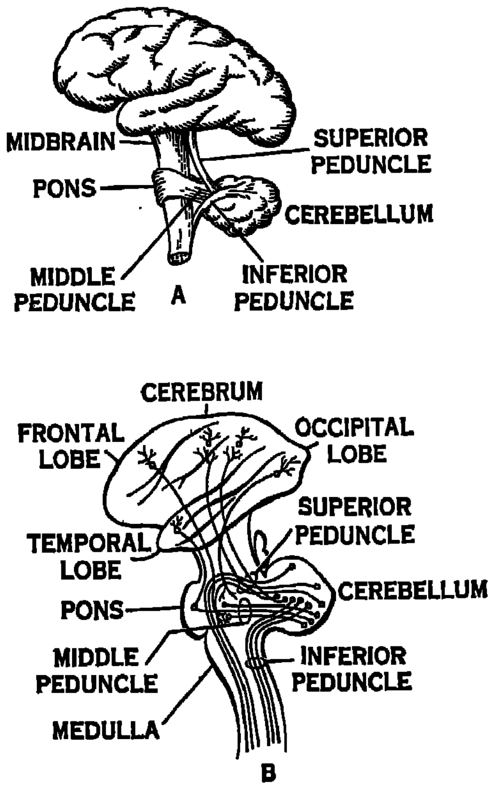


FIG. 32.18. The peduncles of the cerebellum. *A*, general view. The different parts of the brain have been separated to show the cerebellar peduncles more clearly. *B*, showing how nerve cells of the cerebellum connect with cells in the pons, medulla, and cord.

so eventually with the various parts of the body. The information transmitted to the cerebellum from the semicircular canals is probably of greatest importance with regard to maintaining the correct position of the head in space, but afferent impulses received from the eyes and the neck muscles are also essential. Falling backward or to one side or the other is a common manifestation of disordered cerebellar function. The impulses which the cerebellum transmits to the muscles do not themselves induce movements, but they contribute to the maintenance of muscular tension (tone) and in

this way reinforce voluntary motor impulses discharged from the motor area of the cerebral cortex (p. 302). Thus muscular movements are rendered surer and more forceful. The muscular movements of a subject of cerebellar disease or injury are, therefore, uncertain, often tremulous, and weak.

The functions of the cerebellum may be summed up as follows:

1. To keep the muscles in a normal state of tension or tautness.
2. To reinforce the action of the motor area of the cerebral cortex.
3. The two foregoing functions allow muscular movements to be nicely gauged and to be carried out with the usual smoothness, precision, and strength.

The Electroencephalogram

The electroencephalogram is a record of the electrical currents produced by the brain. The currents are picked up by means of

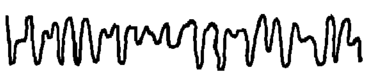


Fig. 32.19. A normal electroencephalogram with waves somewhat enlarged. Only *alpha* waves are shown.

contacts placed on the shaved head or through needles which penetrate beneath the scalp. The contacts or needle electrodes are connected by wires to a sensitive electrical recording apparatus. The record shows a series of small waves; that from a normal person is shown in Figure 32.19. Waves of three different frequencies, called *alpha, beta,* and *delta* can be distinguished. The most rapid (beta waves) have a frequency of from 25 to 50 per second; the slowest (delta waves) have a frequency of 1 to 5 per second. The frequency of the alpha waves is around 10 per second.

In disease of the brain the electroencephalogram may show variations from the normal which enable it to be used as an aid in the diagnosis of certain intracranial conditions—e.g., epilepsy, tumor, etc. The normal electroencephalogram is influenced by sleep, mental activity, and visual stimulation. Characteristic features can also be distinguished in the waves recorded from the skull overlying different regions of the cerebrum.

chapter 33

THE AUTONOMIC NERVOUS SYSTEM. THE PHYSIOLOGY OF SLEEP

The Autonomic or Involuntary Nervous System

The terms *autonomic* and *involuntary* describe a part of the nervous system which acts largely independently of the rest of the nervous system and the effects of which are beyond the control of the will. For the most part we are also unaware of its activities. It conveys messages constantly from various organs to its centers in the brain and spinal cord, from which in turn impulses are transmitted to every part of the body. The autonomic nervous system consists of two main divisions: (1) the *sympathetic* and (2) the *parasympathetic*. The main controlling center for each division consists of a separate and distinct group of nerve cells situated in that part of the base of the brain known as the *hypothalamus* (p. 423). Both these parts of the autonomic nervous system include an arrangement of nerve cells and their processes lying *outside* the central nervous system but with which fibers arising *within* the brain and cord make connection. These connections differ for each division and will be described separately.

The sympathetic nervous system.—The most noticeable part of this division consists of two long cords of nervous tissue, which descend one on each side of the vertebral column. These nerve cords have little swellings upon them, like knots or beads. Each swelling is called a *ganglion*. The "beaded" nerve trunk itself is called the *gangliated cord* (Plate VI*a*). A ganglion is a general term which means simply a separate group of nerve cells.[1] The ganglia

[1] The term is applied most commonly to collections of nerve cells lying outside the central nervous system.

of the sympathetic, therefore, contain a number of nerve cell bodies, and the connecting cord between the ganglia is simply the nerve fibers coming to and going from the ganglion cells.

All sympathetic impulses, no matter what part of the body they ultimately reach, leave the thoracic and upper lumbar regions of the spinal cord. The fibers along which the impulses are conducted from the cord are the axons of cells within its gray matter, and they make connections (*synapses*) with nerve cells in the ganglia (Fig. 33.2). A fresh impulse is discharged by the ganglion cell along its axon to blood vessel, sweat gland, smooth muscle, etc. The pathway along which sympathetic impulses must travel in order to reach their destination consists, therefore, of two links. The first link (along which it reaches the ganglion) is called the *preganglionic fiber,* and the second link, the *postganglionic fiber.*

The roots of each spinal nerve are connected to the nearest ganglion by two short, slender arms called *rami communicantes* (singular, *ramus communicans*). The arms connecting the ganglia with the anterior roots are composed of preganglionic fibers and, having a glistening white appearance, are called *white* rami communicantes. Those which join with the posterior roots, being of a duller color, are called *gray* rami; they are composed of postganglionic fibers. The fibers of the gray rami are continued into the spinal nerve trunk and, mingling with its other fibers, are distributed to the skin, blood vessels, and sweat glands. But by no means do all the postganglionic fibers enter the spinal nerves. Some pass directly as a network along the blood vessels to the head and lungs and by long slender nerve trunks to the heart (accelerator nerves, p. 106).

Sympathetic fibers to the abdominal organs for the most part take a different course from either of the two just described. The *preganglionic* fibers do not connect with cells in the gangliated cord but pass through them to isolated ganglia placed in closer proximity to the abdominal structures. From here strands of postganglionic fibers (which correspond to the gray rami) are distributed to blood vessels, smooth muscle of hollow organs (e.g., stomach, intestines, and bladder) liver, pancreas, and other glands. For the sake of simplicity single fibers only are shown in Figure 33.1. Consult also Plate VI*a.*

"Sympathetic" is scarcely a suitable name for this nervous system, for the word implies feeling and consciousness, and it is with just

these that the sympathetic is not concerned; for, as mentioned above, it carries messages of which the higher centers of the brain have little knowledge. Nerves of this system speed up the heart (p. 106) and slow the movements of the stomach and intestines. They control the secretion of several glands (e.g., salivary and sweat glands).

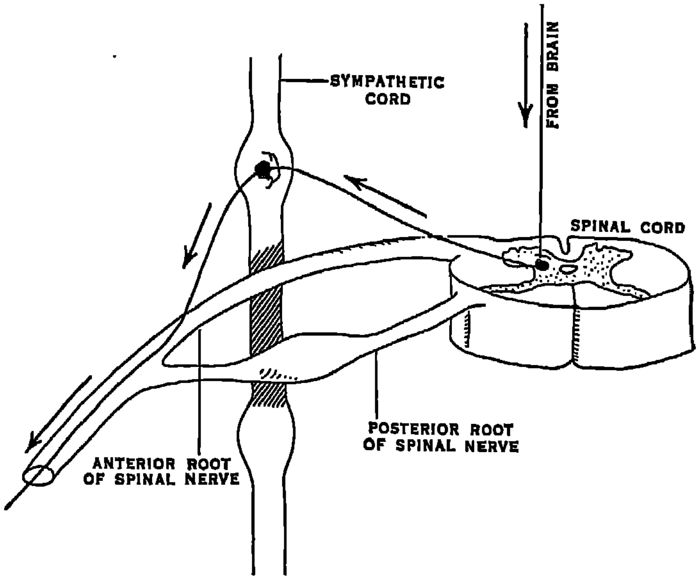


Fig. 33.1. Diagram of the connections of a nerve fiber of the sympathetic nervous system. The arrows indicate the course taken by the impulses from the brain through the spinal cord then along a fiber (preganglionic) to a sympathetic ganglion; here a nerve cell picks up the message and transmits it along its axon (postganglionic fiber), which enters a spinal nerve.

They also transmit impulses which constrict the small blood vessels (vasoconstrictor nerves, p. 108). It is easy to see, nevertheless, how the sympathetic system got its name, for the messages which it carries cause the outward and visible signs of our feelings. The play of our emotions is due to the sympathetic system "pulling the strings." Impulses to the blood vessels may cause the skin to pale or redden. We all know how often it plays us false and tells our inmost thoughts—our anger, love, or fear—by a blush or a sudden pallor. The pupils of the eyes dilate in fear and contract in anger, the flow of saliva may dry up, and the tongue "cleaves to the roof

of the mouth." The skin "creeps," the hair stands on end. Though the latter expression is common in everyday language, there is no basis in fact that such an action occurs in man; but we know that it does occur in the cat and in some other animals. The quills of the porcupine also rise when the animal is frightened and put upon the defensive. So, too, do the feathers of an angry bird. These effects upon hair, quills, and feathers are brought about by the contraction of small muscles in the skin, similar to those in our own skins which give us "goose flesh" or the "creeps" up the back when we are very frightened. These muscles receive impulses from the sympathetic system.

If the reader will turn to page 425, he will find that the secretion of the adrenal gland causes effects similar to those caused by the sympathetic system.

The parasympathetic nervous system.—There are several nerves belonging to the parasympathetic nervous system, but the chief one is the *vagus*. We have already seen on page 105 that this nerve arises in the medulla oblongata and descends in the neck to the thorax and abdomen. It sends messages which slow the heart. The vagus also increases the movements of the stomach, small intestine, and first third or so of the large intestine. It sends fibers to the lungs which cause the narrowing of the fine air tubes (the bronchioles) and to various digestive glands in the abdomen. The *pelvic nerve*, another nerve of the parasympathetic division, arises from the sacral region of the spinal cord and sends branches to the large intestine and other organs of the pelvic region. It increases the movements of the bladder and the last two thirds of the colon.

Certain structures in the head—the pupil, the salivary glands and the blood vessels of the brain—are supplied with parasympathetic as well as with sympathetic fibers. The parasympathetic fibers to the pupil are constrictor in their action; they arise from cells in the midbrain and reach the pupil through the third cranial nerve. The salivary glands receive their parasympathetic fibers through the facial and glossopharyngeal nerves. The facial nerve also carries parasympathetic fibers which dilate the vessels of the brain.

The reader has noticed, no doubt, that the two divisions of the autonomic nervous system are in many instances opposed in their actions. Thus the sympathetic dilates the pupil whereas the parasympathetic constricts it. The vagus slows the heart rate, whereas

the sympathetic increases it. The intestinal movements are increased by the parasympathetic (vagus and pelvic nerves) but inhibited by the sympathetic. The behavior at any moment of a structure receiving fibers from these two autonomic divisions is, in most instances, the resultant of their antagonistic effects.

The Physiology of Sleep and Anesthesia

The nerve cells of the central nervous system are ceaselessly receiving and dispatching impulses so long as we remain awake. They must be given rest in order that they may not suffer injury and perhaps permanent damage by fatigue. Sleep alone can give rest to the nerve cells and allow them to restore their energy for the next day's work. The greater the amount of work done during the day, whether mental or muscular, the longer is the period of sleep required, and young people require much more sleep than do older persons. A healthy newborn baby sleeps for nearly 24 hours, waking only to be fed; but, as the baby grows older, less time is spent in sleep. He stays awake for a time to become acquainted with the world about him, and kicks and cries to get exercise. Older children, even until they are in their teens, should spend from 10 to 12 hours in sound sleep. The body cannot be well unless the nervous system is healthy, for it directs and controls most of the actions and functions of the body. And the nervous system cannot remain healthy if it does not get plenty of rest. A full-grown person requires 8 or 9 hours of sleep—though some persons seem to require less. A person will die much sooner from lack of sleep than from lack of food.

Several functions of the body are reduced to their lowest value during sleep. The pulse is from 15 to 20 beats slower than during rest in the waking state. The blood pressure is also reduced by several millimeters of mercury. The metabolism is at the lowest level possible in health; it is below the basal value (p. 227). The volume of urine is less, but the urine is more highly concentrated. Certain other functions, such as gastric secretion, the movements of the stomach and intestines, and the secretion of sweat, are increased. The pupils are dilated and the skin flushed.

What makes us sleep?—Many theories have been suggested to explain sleep, but it must be admitted that little is known of the

changes in the brain which bring it on. It may be perhaps that a reduction in the blood supply to the brain is a factor. Fatigue may in some way cause less blood to pass through the head. We know that we *do* become sleepy after a meal, when a great part of the blood goes to the stomach for the digestion of the food. It is well known, too, that a hot room, which dilates the vessels in the skin and which might be expected to divert blood from the brain, makes one feel tired and drowsy.

It is probable, however, that a diminished blood supply to the brain, though perhaps a contributing factor, is not one of first importance in inducing sleep. It is more likely that sleep ensues as a result of fatigue of the nerve cells of the sensory area of the cortex or because they are inhibited by some other part of the brain, and as a consequence are less easily aroused to activity by sensory impulses. In the waking state impulses are ceaselessly streaming into the cortex from receptors in skin, muscles, eyes, ears, etc., and maintaining it in a state of activity. Therefore, if the cortex is less responsive to such stimulation, and at the same time the sensory impulses are less frequent, sleep follows. We all know that we must reduce the stimulation of our various receptors to a minimum before we can go to sleep. First, the eyes are put at rest, the lights are turned out or, if the room cannot be darkened, the eyes are shielded by closing the lids. Our surroundings must also be as quiet as possible; if there is any noise we may find it necessary to plug our ears with absorbent cotton. When we lie down we completely relax all our muscles, which means that the frequency of the impulses from the proprioceptors (p. 276) in muscles, tendons, and joints is lessened. The stimulation of the sense organ of the semicircular canals is largely abolished as well. The stimulation of the skin receptors is also diminished; the surface upon which we lie must be soft and we should be neither too warm nor too cool. It is an unsettled question whether some remote part of the brain exerts a depressing or inhibiting influence upon the sensory areas of the cerebral cortex and thereby induces sleep. Some believe that the region at the base of the brain, known as the *hypothalamus* (p. 423), exerts such an influence. It has been reported that electrical stimulation of this region in animals induces sleep.

Anesthesia.—Certain drugs called anesthetics, such as *ether* and *chloroform,* when inhaled, are absorbed into the blood and depress

the activity of the cells of the cerebral cortex. They induce a state resembling deep sleep except that the subject is completely unconscious and cannot be roused until the effect of the anesthetic has passed off. The drug causes complete blockage of sensory impulses, including those which in the conscious person would cause intolerable pain. The state of anesthesia is divided into four stages, according to its depth.

The *first stage*—when the anesthetic is commencing to exert its effect—is usually marked by excitement. Consciousness is not completely lost and some voluntary movement is possible. The patient may cry out or struggle, perhaps violently. In the *second stage* consciousness is lost but the reflexes are retained and any strong stimulus, especially if painful, may therefore cause a violent muscular reaction; the pupil still reacts to light. In the *third stage,* which is required for surgical operations, the reflexes are lost and the muscles fully relaxed. There is apparently complete blockage of sensory impulses to the higher centers of the brain. The pupils are contracted. The *fourth stage* is one of overdosage and is therefore dangerous to life, for the anesthetic is exerting a paralyzing action upon the vital (respiratory, cardiac and vasomotor) nervous centers. The respirations are rapid and shallow; the heart beat is rapid, weak, and perhaps irregular; the pupil is dilated.

Drugs, such as *morphine* and *chloral,* when taken by injection or by mouth, produce a stuporous state and, in overdosage, complete unconsciousness amounting to coma with depression of the vital centers of the brain. They are called *narcotics.* Other drugs such as *veronal* and *luminal,* which depress the excitability of the cortex to sensory impulses and in the usual dosage induce a more natural sleep, are called *hypnotics* or *soporifics.*

part VIII

The Special Senses

chapter 34

THE PHYSIOLOGY OF VISION

General Description of the Organ of Sight

The eyes have developed from hollow outgrowths of the fore part of the brain. The adult human eye is almost spherical in shape and about 1 inch in diameter (Fig. 34.1). A clear, circular window

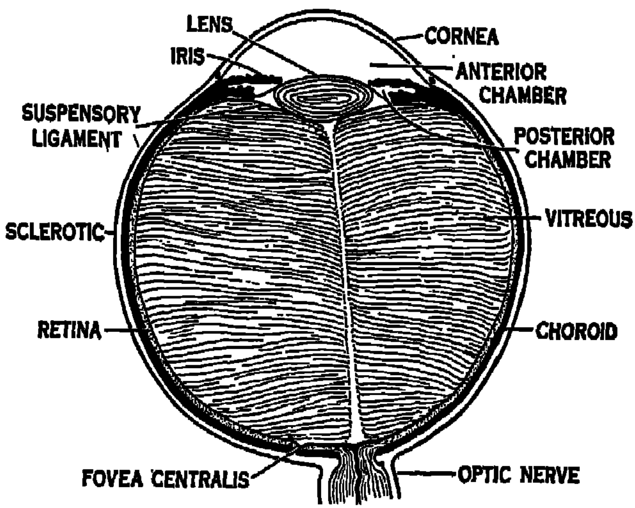


Fig. 34.1. Diagram of a section through the eyeball to show its different parts.

about ½ inch across, situated on its front (anterior) wall and called the *cornea* permits rays of light to pass through the interior of the eye and fall upon the *retina*. The retina is the sensitive tissue which lines the back (posterior) wall. A compact, rounded bundle of nerve fibers—the *optic nerve*—issues from the posterior pole of the eyeball and carries nerve impulses to the brain. Upon arriving

at their destination, these impulses give rise to the sensation which we know as sight or vision. In the protection of such a valuable organ as the eye nature has taken every possible precaution. The eye, except for a small part of its circumference in front, is enclosed in a bony case—the eye socket or *orbital cavity.* It is separated, however, from the unyielding bone by a thick layer of loose fat upon which it is cushioned, so that a force striking the delicately struc-

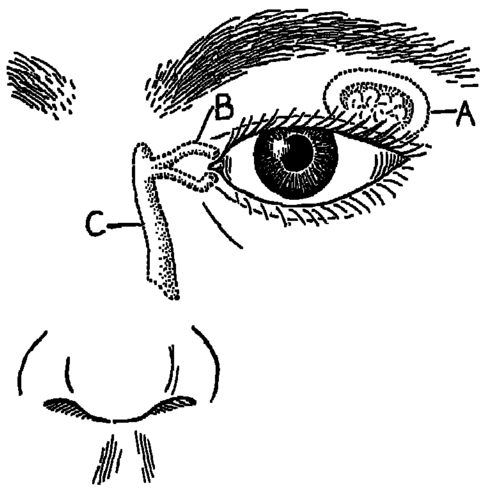


FIG. 34.2. The lachrymal apparatus. *A,* lachrymal gland; *B,* lachrymal ducts: *C,* nasal duct.

tured globe is less likely to damage it. The eyelids, as we know, are able at an instant's warning to close over the front part of the eye and protect it when injury threatens (Plate VI*b*).

Small muscles stretch between the wall of the bony cavity and various points in the circumference of the globe, and by their contractions pull upon one or other side of the eye to roll it about in its bed. The eyelids are lined by a delicate membrane called the *conjunctiva.* At the upper limit of the upper eyelid and at the lower limit of the lower lid the membrane becomes folded over, to pass from the inner surfaces of the lids on to the front of the eyeball, which it completely covers. When the lids move up and down, these two folds of membranes slide over each other. The surfaces are kept lubricated by a small amount of tear fluid, which is con-

tinuously secreted by a gland—the *lachrymal gland*—lying under the shelter of the bone forming the upper and outer part of the eye socket. The tears, after flowing over the surface of the eye, are drained away from its inner angle by small tubes—the *lachrymal ducts*—and pass into the nose. If it were not for the constant washing and lubrication of the surface of the eyeball by the tears, the delicate covering membrane would soon become dry and inflamed, and destruction of the eye would result (Fig. 34.2).

The Structure of the Wall of the Eye

The wall of the eye is composed of three layers or coats—an outer, a middle, and an inner (Fig. 34.1).

The *outer layer* or *sclerotic coat* is made of a tough and dense *fibrous material, which preserves the form of the globe and protects* the more delicate structures within. Part of this coat may be seen in the front of your own eye, where it forms what we know as the *white of the eye*. In front, and in the very center of the sclerotic coat, is a circular window called the *cornea*. But this "window of the eye," though apparently as clear as glass is not as homogeneous, for under the microscope it can be seen to be made up of several rows of flat cells, laid one on top of the other and cemented together. Should the surface of the cornea be cut or seriously injured in any way, a scar will form, which, if large and in the line of sight, will cause blindness in the affected eye.

The *middle layer* or *choroid coat* carries the greatest number of the blood vessels with which the eye is supplied. It shows a fine network of small arteries and veins (Fig. 34.3). Its weave of vessels, like a dark red carpet, completely covers the eyeball, except in front, where a small punched-out hole is seen. This round opening, which lies behind the center of the cornea, is, of course, familiar to everyone. It is known as the *pupil of the eye*. The circular band of the choroid coat surrounding the pupil is also familiar to all, for it is this which gives to the eye its brown, blue, black, or hazel color. This colored band has been named the *iris*, after the mythical goddess of the rainbow. If we think of a rainbow mirrored in a pool, the name perhaps is not inept.

The inner layer or retina.—The retina lines the interior of the eyeball, and may be described as a layer of tissue highly specialized

to convert the energy of light waves into nerve impulses which are transmitted by the optic nerve to the brain. If a section of the retina is examined under the microscope, several layers can be distinguished; but, though the layers have each their own special features, they must be looked upon as being in close connection with

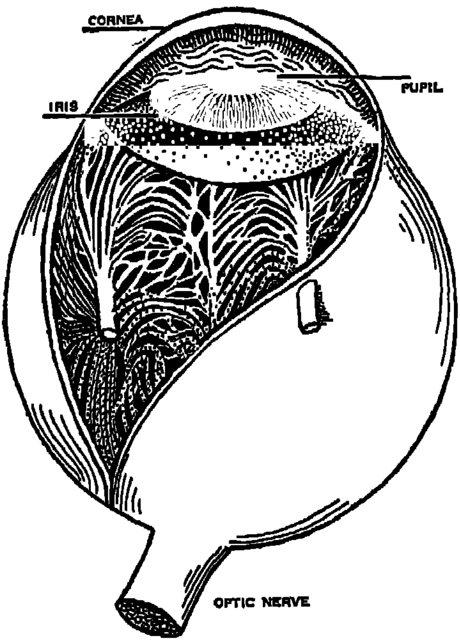


FIG. 34.3. The eyeball with part of the sclerotic coat cut away to show the choroid and its network of veins.

one another and as forming together a single structure for receiving light and converting it into messages of sight.

As will be seen when its cell layers are described, the retina is essentially a nervous structure. Its origin from the brain has been mentioned.

THE MINUTE STRUCTURE OF THE RETINA

The chief layers to be distinguished in the retina are shown in Figure 34.4. In order from front to back, that is, from the inside of the eyeball outward, they are as follows:

1. Layer of nerve fibers.
2. Layer of ganglion cells.
3. Inner and outer molecular layers.
4. Layer of rods and cones.
5. Layer of pigment cells.

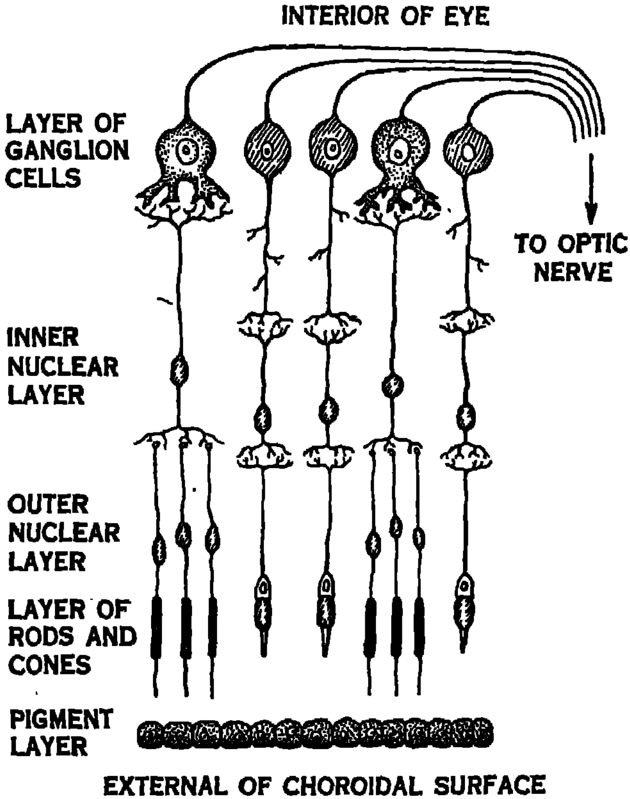


FIG. 34.4. Diagram to show the chief layers of the retina.

The layer of nerve fibers.—These fibers are the axons (p. 270) of the ganglion cells composing the layer (2) lying just beneath. The ganglion cells give off these long fibers, which, after passing forward for a short distance, turn horizontally and form a felted layer above the cells from which they arose. The fibers, about 500,000 in number, all converge to one point—the center of the back of the eye-

ball—like streams of water into a vortex. Here they are collected into a rounded bundle to form the *optic nerve.*

The ganglion cells forming the second layer of the retina are, for the most part, large plump cells whose axons form the first layer just mentioned. Their dendritic processes are directed outward to form synaptic junctions (p. 280) with cells of the internal molecular layer.

The rods and cones.—These curiously shaped cells which are shown diagrammatically in Figures 34.4 and 34.5 form the outermost layer of the retina but one. They are the receptors (p. 275) of vision; when stimulated by light they cause impulses to be set up in the nerve cells, which are transmitted along the optic nerve to the brain. In most animals, the cones are in greatest numbers in the *fovea centrallis* (p. 331), that part of the retina which is concerned with acute vision—i.e., with the perception of the finer details of the visual image. In man, this region contains only cones. The cones are also responsible for the appreciation of color. In other parts of the human retina the cones are intermingled with the rods but are found in progressively fewer numbers farther and farther from the fovea centralis (*extrafoveal region*); the rods increase in number as the cones decrease. These rod receptors are concerned only with the perception of light and shade. They give rise to no sensation of color, but they are very sensitive to light of low intensity. It is through the medium of the rods that objects can be seen in dim light. The threshold of the cones is much higher—that is, they require a stronger light to stimulate them. That is the reason why a faintly illuminated object, such as a small star, often cannot be seen if we look at it directly (foveal vision). Only when we turn our eyes a little to one side so that its image falls upon the extrafoveal region of the retina does it become visible; we see it "out of the corner of the eye."

The insensitivity of the cones to weak illumination and the inability to perceive color by means of the rods account for our blindness to color in twilight. Our surroundings are then seen only as light and shade, white or gray and black. The rods, though they give no sensation of color when an image of a green, blue, or yellow object falls upon them, are stimulated, nevertheless, and the object appears gray. But dark red light fails to stimulate the rods at all;

the absence of any kind of visual stimulation then gives a sensation of black. In their sensitivity the rods resemble an ordinary photographic film.

The outer sections of the rods contain a red pigment called *visual purple* or *rhodopsin*. This is decomposed by light into an *orange-*

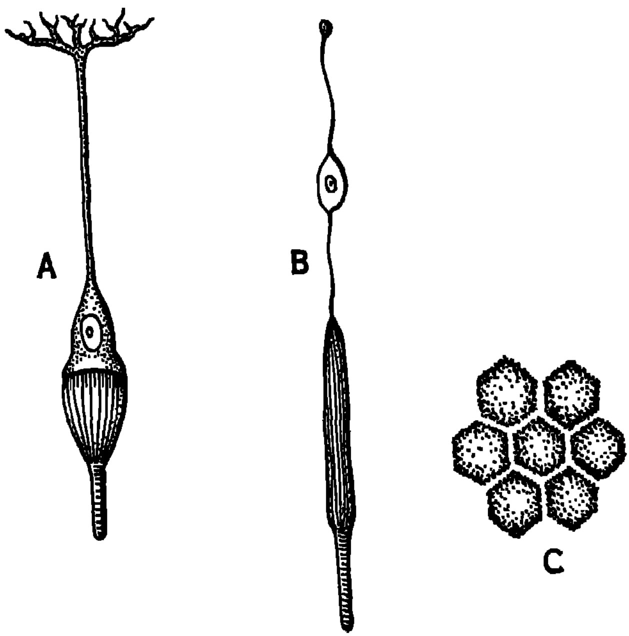


FIG. 34.5. Cells from the outer two layers of the retina. *A*, a cone; *B*, a rod; *C*, pigment cells.

yellow substance[1] and upon further exposure into *vitamin A* and a *protein*. These latter products are colorless; it is usually said, therefore, that visual purple is "bleached" by light. Reconversion of vitamin A and protein to visual purple takes place in darkness. It is through this photochemical change that the rods serve as visual

[1] This substance consists of a carotene-like pigment and protein and has been called *retinene*. The cycle of changes is as follows:

Rhodopsin

Dark ↗ ↘ Light

vitamin A + protein ← retinene + protein

receptors. The changes in the light-sensitive substance in some way causes impulses to be set up in the nerve cells of the retina. A constant supply of vitamin A must be brought to the retina in the circulation in order for a rapid reformation of visual purple to occur, since a certain amount of the vitamin is inevitably destroyed in the bleaching process. This is the reason why persons whose diets are deficient in vitamin A are unable to see clearly in dim light. This visual defect is called *night-blindness,* or *nyctalopia* (see p. 249).

The bleaching of visual purple by light can be shown very strikingly in the excised eye of an animal. The animal is kept in the

FIG. 34.6. Effects produced in a rabbit's eye by casting an image of a window upon the retina. The image of the bright panes bleaches the visual purple. A picture produced in this way is called an *optogram.* (*After Howell.*)

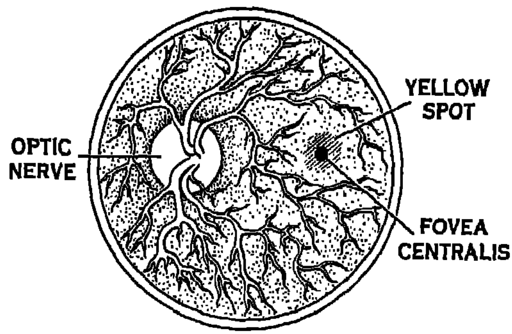
dark for a time to allow complete restoration of the visual purple, and the eye is removed in darkness. Then, as in taking a photograph, the eye is directed toward an object with strong contrasts of light and shade, such as a window sash against a bright sky. Thus, an image is thrown upon the retina which can be seen when the eye is opened in a dim light. The picture, known as an *optogram,* was printed upon the retina because the visual purple was bleached only where the bright parts of the image fell (Fig. 34.6).

Though the existence of a light-sensitive pigment has not been proved for the cones of the retina, it is probable that their function too is dependent upon a photochemical process.

Other layers of the retina.—Between the rods and cones on the one hand and the ganglion cells on the other are situated numerous nerve cells which form functional links between these two sets of retinal elements. Their bodies form a well defined layer known as the inner *molecular layer.* Their axons connect with the dendrons of the ganglion cells and their dendrons with the fibers of the rods and cones. Thus, impulses set up by stimulation of the visual receptors are transmitted to the ganglion cells and thence along the axons of the latter (optic nerve fibers) to the brain. The outer

molecular layer consists simply of the expansions (nuclei) on the rod fibers. The *pigment layer* is a single row of irregularly shaped cells containing granules of a dark pigment. They lie in contact with the outer ends of the rods and cones. They probably serve like the black paint in the interior of the camera, to absorb light rays and prevent blurring of the retinal image by rays of reflected light. It will be noted that in order for light to reach and stimu-

FIG. 34.7. The interior of the posterior wall of the left eyeball as seen from in front. The entrance of the optic nerve and the retinal blood vessels are clearly shown. This part of the eye can be seen in a living person by means of an instrument known as an *ophthalmoscope*, which throws a light through the pupil upon the retina.



late the rods and cones it must pass through all the other layers of the retina except the pigment layer.

The yellow spot and fovea centralis.—During waking hours the eyes are incessantly making fine, often imperceptible, movements from side to side or up and down. The main purpose of these movements is to bring the images of objects onto that part of the retina which is capable of the most acute vision. If the reader will place some object and look directly at it, he will be able to describe it in detail. But other objects well to one side, above, or below his line of vision are seen only vaguely; he can scarcely tell their shapes or their colors. The part of the retina capable of acute vision and upon which images are focused in order to see things clearly, is a very small depressed area called the *fovea centralis*. In man this area contains only cones and is therefore blind in very dim light (p. 328). In man it is only about half a millimeter across. It is hard to realize that objects in the outside world cast images upon

the retina so small as to fit upon such a tiny spot. Indeed, an object which casts an image whose diameter is measured in thousandths of a millimeter is clearly visible.

The fovea centralis lies in the center of a large yellow area—the *yellow spot,* or *macula lutea,* which are simply the Latin words for the same thing. The yellow spot, with its central pit or fovea, lies to the outer side of the optic nerve (Fig. 34.7).

Though the retina is stimulated most effectively by light rays, other types of stimulus will produce visual sensations. In whatever manner the retina is stimulated, the sensation experienced is always a visual one (p. 276). A blow on the eyeball (mechanical stimulus), for instance, causes one to see flashes of light in the form of circles, streaks, or "stars."

chapter 35

THE PHYSIOLOGY OF VISION (Continued)

General Optical Principles. The Crystalline Lens. Accommodation of the Eye

The reflection and absorption of light.—Light travels in waves at a speed of nearly 190,000 miles per second. The waves or vibrations of light are of different lengths, but all are extremely short, being measured in millionths or ten millionths of a millimeter.[1] Since light waves travel at such an enormous speed, immense numbers must be reflected to our eyes each second from the various objects around us.

The color of any light depends upon the length of the waves of which it is composed. The waves of red light are the longest (700 to 800 mμ) that cause a visual sensation. Waves longer than these are felt as heat, or are known as radio waves, which, as everyone knows, are measured in meters instead millionths of millimeters. The waves of violet light are the shortest which stimulate the retina. Shorter waves than these—the ultraviolet—have powerful effects upon the body, but they do not excite the retina to produce the sensation of sight. Waves still shorter than the ultraviolet are the X rays. The waves of orange light are shorter (650 mμ) than the red rays, but are longer than those of yellow (600 mμ) or of green (500 to 550 mμ). The waves of blue light (about 450 mμ) and of violet (around 400 mμ) are shorter still. Therefore, starting at the red side of the rainbow—i.e., at the left hand end of the *spectrum* (p. 344)—the different colors are laid out side by side in the order

[1] A millionth of a millimeter is a millimicron (abbreviated mμ); a ten millionth of a millimeter is called an angstrom unit. Either unit may be used to express the wave lengths of light.

of their wave lengths. The red is on the extreme left, violet on the extreme right; orange, yellow, green and blue, in this order, lie in between (Plate VII*d* A).

Waves of light continue to travel from their source until they strike some material through which they cannot pass. Some of the waves may then be reflected; the rest are absorbed. It is the reflected waves alone which enter the eye and through which the reflecting objects are seen. Light waves of different lengths are not always reflected to the same degree (Fig. 35.1). The surfaces of some objects reflect mainly the long red waves and absorb the shorter

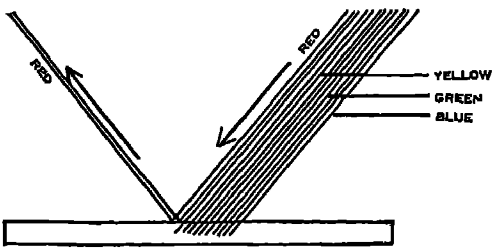


FIG. 35.1. Diagram to illustrate the absorption and reflection of light from the surface of a red object. Note that all the constituent rays of white light are absorbed except some of the red, which are reflected.

waves of orange, yellow, blue, green and violet. Such an object therefore appears red. If the reflected light consists mainly of the shorter waves—orange, yellow, green—the object is of the corresponding color. If all wave lengths are reflected equally, the object appears white. A surface which absorbs completely, or nearly so, all the light which falls upon it, appears black, for there are no reflected waves to stimulate the retina, and the sensation of blackness is simply the absence of any visual stimulation. A material through which light passes with little or no obstruction—i.e., one which neither reflects nor absorbs light—is transparent. Some perfectly transparent materials such as air, or clear glass placed at a certain angle, are invisible.

Refraction of light.—Rays of light become bent from their straight paths when they pass from air into some other transparent material, such as glass or water, or, vice versa, when they pass through one of these materials into air. This bending of the rays of light is called *refraction*. We have all noticed that a stick partly submerged in water appears broken at the point where the air and water meet. The illusion is due to the fact that the rays of light reflected from

the submerged portion of the stick become bent or *refracted* in passing from the water into the air to meet our eyes (see Fig. 35.2).

A glass prism—i.e., a wedge-shaped block of glass—refracts unequally the rays of light transmitted through its different parts. Those rays transmitted nearer the apex are refracted more strongly than those transmitted nearer the base. All rays are bent toward the base of the prism. Therefore, if two prisms are placed base to base, the light rays are converged and at a certain distance from the glass surfaces are brought to one spot or focus. Now a lens with two convex surfaces (Fig. 35.3) is in reality composed of two prisms placed in such a position. A lens with two concave surfaces (Fig. 35.4), on the other hand, bends the rays away from one another, acting like two prisms placed apex to apex.

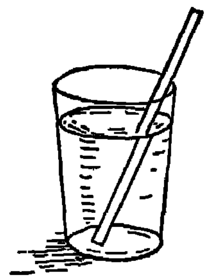


FIG. 35.2. The refraction of light.

The converging action of a convex lens can be shown very simply by means of an ordinary "burning glass." The sun's rays travel in straight parallel lines but in passing through the glass are refracted and can be brought to a focus as shown by a small spot of bright light. The heat rays are also concentrated, and the temperature of the object upon which they fall may be raised to the point at which it ignites. The more curved—i.e.,

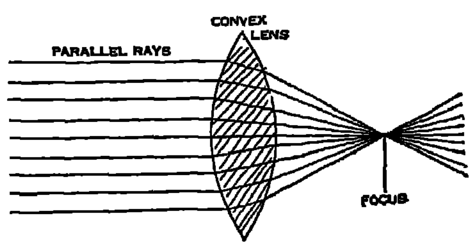


FIG. 35.3. The convergence of light by a convex lens.

the more convex—the surface of any lens, the greater is its converging power and, as a consequence, the shorter is the distance from the lens at which the rays are brought to a focus.

Not only sunlight and rays from other sources a great distance away, but rays emitted from any source except those at very short distances travel in practically parallel lines. Rays from a near source

are divergent or radiating and must therefore be refracted more strongly in order to bring them to a focus at the same distance from the lens as parallel rays are focused (Fig. 35.5). In order to do this the lens must be more convex. The distance from the lens at which parallel rays are focused is called the focal length of the lens; the

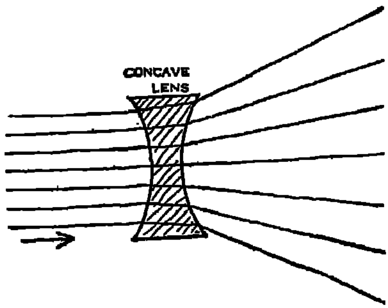


FIG. 35.4. Diverging effect of a concave lens upon parallel rays. Radiating rays are made more divergent by a concave lens.

shorter its focal length the greater, therefore, is the converging power of a lens.

The eye as a camera.—In the invention of the camera the main parts of the eye have been imitated very closely. A lens serves to focus the rays of light upon the sensitive film. The light coming from an object in front of the camera passes through the lens, and

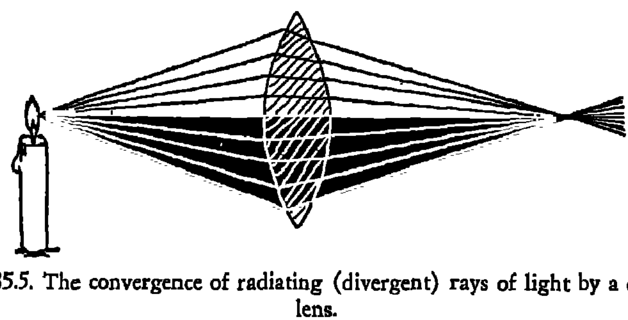


FIG. 35.5. The convergence of radiating (divergent) rays of light by a convex lens.

is brought to a focus and forms a small image of the object upon the film. In the eye also there is a lens which brings the rays of light from objects in the outside world to a focus upon the retina, which, like the photographic film, is sensitive to light. The camera has a diaphragm, or "stop," to increase or reduce the amount of

light reaching the film. The eye also is able to control the amount of light entering it. The iris serves this purpose; its opening can be widened or narrowed. The globe of the eye corresponds to the box of the camera; the rays of light pass through this darkened chamber to reach the retina.

The lens of the eye.—The *crystalline lens* is suspended within the eyeball a short distance behind the cornea in a hammock-like structure called the *suspensory ligament.* The lens and the structures surrounding it divide the interior of the eyeball into two compartments. The compartment in front of the lens is filled with a clear watery solution called the *aqueous humor;* the larger compartment behind is occupied by a semifluid material called the *vitreous body.* The crystalline lens is a biconvex disc, but the anterior surface is more strongly curved than the posterior. In health the lens is almost perfectly transparent. When, as sometimes occurs, it becomes semitransparent or opaque, the sight, of course, is lost. Such a condition is spoken of as *cataract.* The cornea also refracts the light, and so acts as an important aid to the lens. The eyes of insects are provided not, like man, with a single lens but with a large number of lenses placed side by side. An object casts a large number of images, nearly though not quite the same, upon the insect's retina.

Accommodation of the eye for near vision.—Rays of light coming from a distant object are parallel, but those coming from a point close to the eyes are radiating or divergent. The parallel rays obviously do not need to be bent so acutely as the radiating rays in order to bring them to a point at the same distance behind the lens. Consequently, if we take a lens which has a certain power to refract light rays, it will be found that the parallel rays from a distant object are brought to a focus at a shorter distance beyond the lens than the radiating rays from a near object (Figs. 35.3 and 35.5).

When, with the bellows type of camera, we wish to take a photograph of an object only a few feet away from the camera front, the bellows must be drawn out so that the lens is further from the film than when a more distant view is being photographed (Fig. 35.6). The reason for this is, of course, that, as just mentioned, the radiating rays from the near object are brought to a focus at a greater distance behind the lens than are parallel rays from a distant object. When the distance from the lens to the film is such that

the rays of light are brought together to form a clear image, the camera is said to be in focus. With the ordinary box camera, which is not provided with the means for moving the lens back and forth, photographs of very near objects cannot be taken unless in front of the original lens another lens is placed which will bend

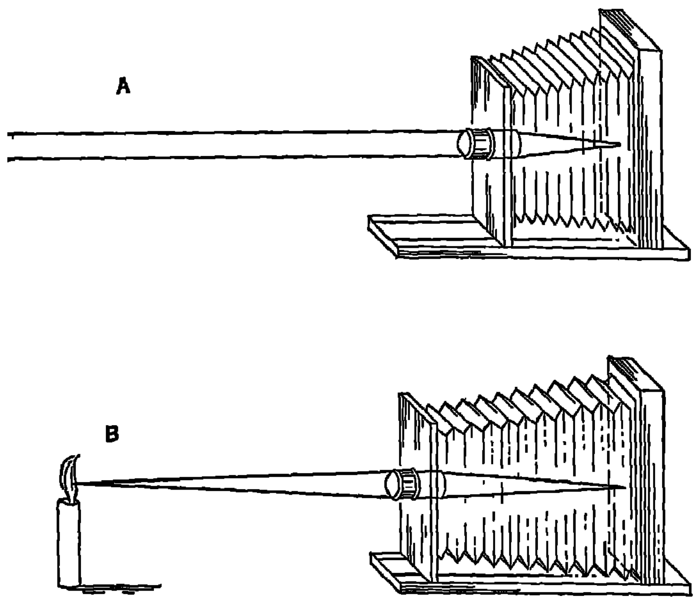


FIG. 35.6. Illustrating how parallel rays (*A*) and diverging rays (*B*) are focused upon the film in a camera of the bellows type. Since the power of the lens cannot be altered, the distance between lens and film must be increased. That is, the film is placed at the new point of focus.

the rays of light more acutely and bring them to a focus upon the film, that is, at the same distance, behind the lens. The addition of an extra lens is equivalent to using a more convex single lens (see Figs. 35.7 and 35.8).

Like the bellows camera, the eye can form clear images upon its sensitive surface—the retina—of either near or distant objects. Unless the eye were provided with some means of adjustment, the view of distant objects might be quite clear, but in reading, writing, or examining small objects the images upon the retina would be out of focus and blurred. In order that the reader may convince him-

self that the eye has this power, let him look at some object near the farther end of the. room. While his eyes are focused for this object, let him bring this page in front of his eyes. The words will appear blurred and indistinct, for the letters are out of focus upon the retina. In an instant, however, he can direct his eyes to the letters, which are immediately seen clearly. This ability to bring

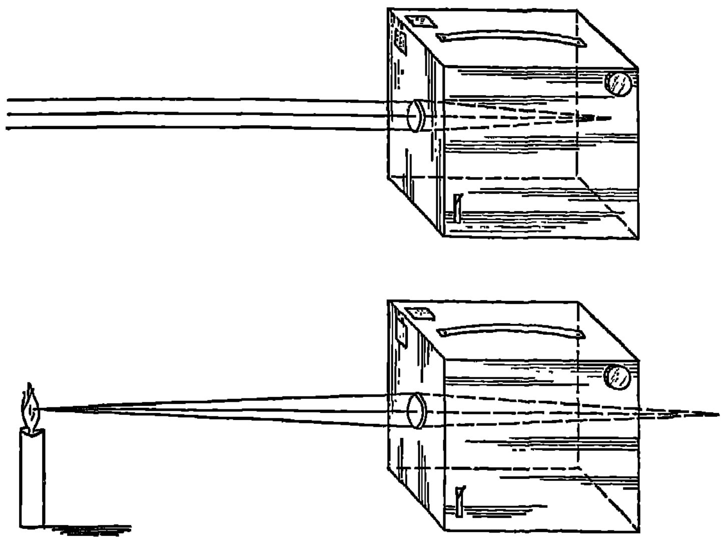


FIG. 35.7. The lens of a box camera can focus parallel rays but cannot focus diverging rays which are cast from a very near object. A blurred image is thrown upon the film.

near objects into focus upon the retina is called the *accommodation of the eye.*

We must next consider how the accommodation is accomplished. The eye cannot, of course, like the bellows camera, move its lens forward or backward [2] and so increase or reduce the distance between the lens and the retina. It resembles more the box camera, in which the lens is placed at a fixed distance from the film. As mentioned above, a near object can be photographed with the box camera only by employing an extra lens, which will aid in bending the radiating or diverging rays of light. The eye, however, cannot

[2] In some classes of fish this method is actually employed, and in certain mollusks accommodation for near vision is brought about by a lengthening of the eyeball.

obtain an extra lens, but it can accomplish the same effect in an instant by increasing the power of its lens. The lens becomes more convex when near objects are viewed, and so bends more

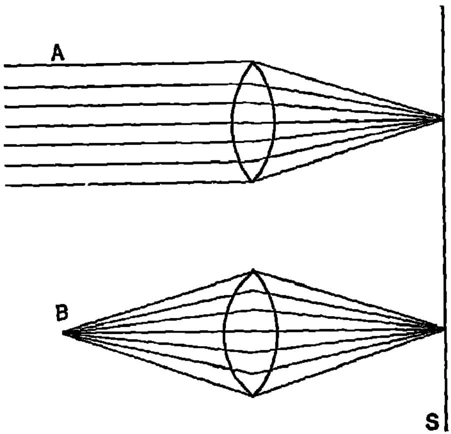


FIG. 35.8. The lens *A* can focus parallel rays to the surface *S* but could not focus diverging rays to the same point. The more convex lens *B* bends light rays more acutely and so can bring the diverging rays from a near object to a focus upon the surface *S*. Compare with Figure 35.9.

strongly the radiating rays and brings them to a focus at the same distance behind the lens as it does the parallel rays. So, in viewing either near or distant objects a clear image is thrown upon the retina (see Figs. 35.8 and 35.9).

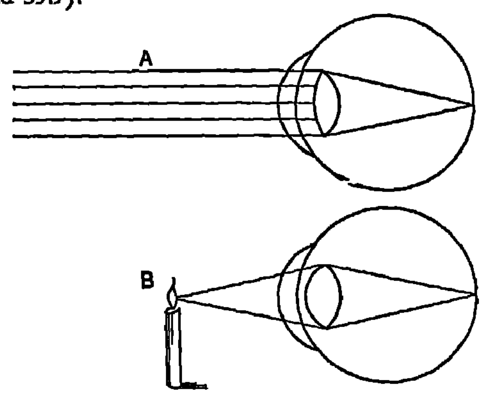


FIG. 35.9. Showing how the eye by increasing the convexity of its lens can focus rays of light from either distant (*A*) or from near objects (*B*) upon the retina.

The shape of the lens is changed in the following way. The lens is an elastic body and is held under slight pressure by the sling-like *suspensory ligament* which completely encloses it. The two ends of the ligament are fastened on either side to the inside of the globe

and indirectly to the delicate *ciliary muscles*. When the eyes are directed to a near object these muscles within the eyeball contract and slacken the ligament by drawing forward its attachments to the wall of the eyeball (see Fig. 35.10). This relieves the flattening pressure upon the lens, which springs into a more curved or bulging shape. This action is similar to the flattening and recoil of a spring or rubber ball, held between the finger and thumb, when the pressure upon it is increased or reduced (see Fig. 35.11). The

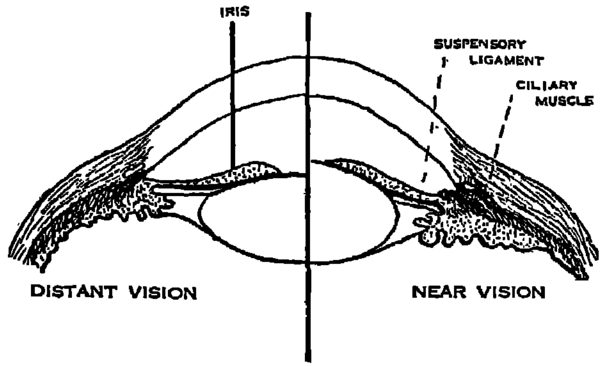


FIG. 35.10. Showing the shape of the crystalline lens for distant and for near vision, respectively. The suspensory ligament and ciliary muscles are shown. (*After Helmholtz.*)

lens of the eye shares with the other tissues of the body the tendency to become less elastic with age. Its surface does not spring forward and become more convex in the usual way when the pressure is relieved. That is the reason why elderly persons have difficulty in accommodating their sight for near objects. They hold a printed page at arm's length in an effort to focus the letters upon the retina. They cannot increase the power of the lens at will. Convex glasses are employed for reading and other fine work. The eye of the elderly is like the box camera; it must seek the aid of an extra lens to bring the light rays from near objects to a focus upon the retina.

The function of the iris.—The iris is made of a delicate, ring-shaped sheet of muscle. The muscle consists of two sets of fibers, one of which is arranged circularly; the other set radiates from the central opening—the *pupil* (Fig. 35.12). Each set of fibers is sup-

plied by a very fine nerve. When the circular fibers contract, like a purse string, the pupil is narrowed. When the radiating fibers shorten, the pupil widens. The diameter of the pupil is larger in dim than in strong light. In darkness the pupils dilate widely. Thus, the iris serves the same purpose for the eye as the diaphragm or "stop" does for the camera; it controls the amount of light which enters the eye. The pupils are also narrowed when the eyes are directed to a near object, but dilate again when they are turned upon a distant view. The reader may verify these facts for himself by alternately shading and exposing the eyes of another person and noticing the changing size of the pupil, and also by having the person direct his vision alternately to a near and a distant object. The pupil dilates with fear and narrows in anger (p. 315). It becomes progressively smaller with age.

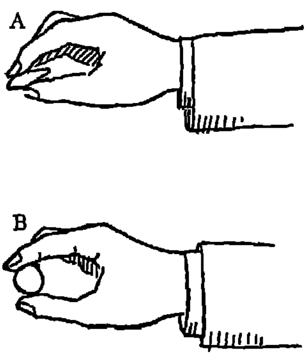


FIG. 35.11. Diagram of a small rubber ball held between finger and thumb to illustrate how the elasticity of the lens causes it to become more convex when the suspensory ligament is slackened. In *A* the ball is compressed by the fingers. In *B* the pressure has been released, and the ball springs back to a more rounded shape. It should be pointed out, however, that only the anterior surface of the lens becomes more convex during the accommodation of the eye. Little or no change occurs in the shape of the posterior surface. (See Figure 35.10.)

The field of vision.—We cannot see an object behind our heads, as we all know. Our field of vision—that is, the actual region in front of us in which we can see objects by turning the head (but not the body) to one or the other side—is about four fifths of a circle of which the head is the center. When the eyes are directed straight ahead the visual field is restricted to a little more than half a circle. If the reader will look straight ahead, hold his two forefingers at arms' length in front and level with his eyes, and then, separating the fingers, sweep them circularly to right and left, he will find that they cannot be seen when they have been carried a little behind a point opposite either ear. The region behind this is spoken of as the blind zone. The bird has no blind zone; as its

eyes are placed upon the side of its head; it can see objects behind almost as well as in front of its body.

The blind spot.—A small object placed at a certain point in front of one eye while the other is closed is invisible because its image

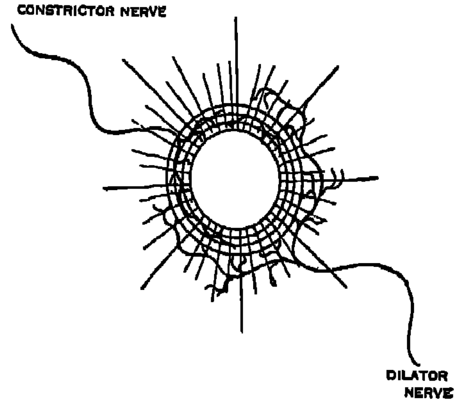


Fig. 35.12. The muscular fibers (circular and radiating) of the iris with their nerve supply.

falls upon that part of the retina occupied by the commencement of the optic nerve (Fig. 34.8). Here the rods and cones are absent. Only the nerve fibers, as they stream together from different parts of the retina, are present in this area, and in consequence it is insensitive to light. The visual receptors—the rods and cones—alone are capable of creating nerve impulses when stimulated by light. The reader is referred to Figure 35.13 for a demonstration of the blind spot in his own eye.

Fig. 35.13. The blind spot. Close the left eye, hold the figure about six inches in front of the right eye, and look steadily at the white disk. Move the book slowly toward the eye until the cross disappears. When this occurs the image of the cross has fallen upon the entrance of the optic nerve from which rods and cones are absent; it is therefore insensitive to light.

chapter 36

COLOR VISION

The theory of color vision.—White light is in reality a combination of several colors—a mixture of red, orange, yellow, green, and blue light rays. The several colors of which it is composed can be separated by means of a glass prism. A prism refracts the waves of red light less than it does the waves of orange light. The orange rays, though bent more than red, are bent less than yellow, and the waves of yellow less than those of green, and so on. The different kinds of waves in white light, therefore, when they pass through the prism, take different paths and fall upon different points of any surface situated beyond (Fig. 36.1). This array of colors is called the *spectrum*. (See Plate VII*d* A.) The diamond owes its flashing beauty to the fact that its surface is cut into small prisms. The colors of the rainbow are created by the raindrops, which act as prisms to split the sunlight and as tiny mirrors to reflect the separate colors to our eyes (Fig. 36.2).

The colors into which white light is split can be recombined to produce white. It is not necessary, however, to employ all the colors of the rainbow or in the fires of the diamond to obtain a white light. It is a well-known fact that not only white light but all the colors in nature can be produced from the three colors, *red, green,* and *blue* (or violet). These are called *primary colors.* If we were to set up three lanterns, one to throw a red, another a green, and the third a violet light, we should be able, by casting upon a screen one, two, or three of these colors blended in suitable combinations, to produce white light or any color we should desire. For example, by blending red, green, and violet lights in proper proportions, white light would be produced. Red and green, together with a very little

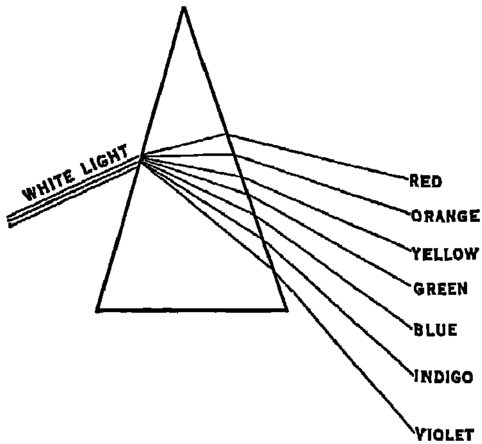


FIG. 36.1. The splitting of white light by a prism into its constituent colors. (See Plate VII*d* A.)

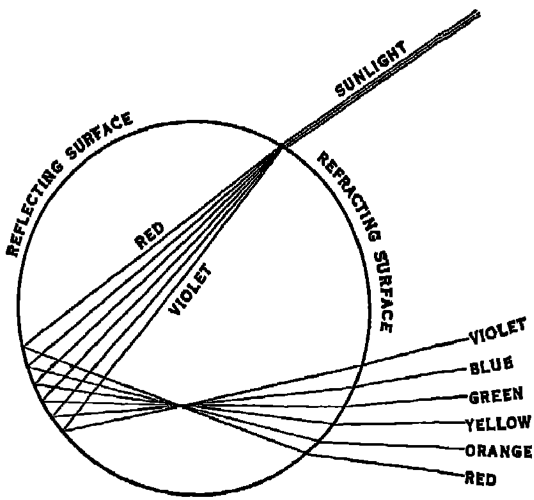


FIG. 36.2. The splitting of sunlight and the reflection of the separated rays by a raindrop.

blue or violet, would produce yellow or orange; green and violet would give blue; red and violet, purple; and so on. Pure red, green, or violet would, of course, be produced by the corresponding single lights used alone.

According to the most widely accepted theory of color vision, the retina possesses three kinds of sensitive cells (cones). One type is stimulated by red, one by green, and the third by violet. When white light falls upon the retina, all these elements are stimulated nearly equally, and a sensation of white is experienced. When a yellow color is seen, the sensation is due to the stimulation of equal numbers of green and red, but very few of the violet elements. If violet and green elements are stimulated, a sensation of blue results. When a large proportion of the elements of green, red, or violet are excited alone, we see green, red, or violet (Plate VII*a*).

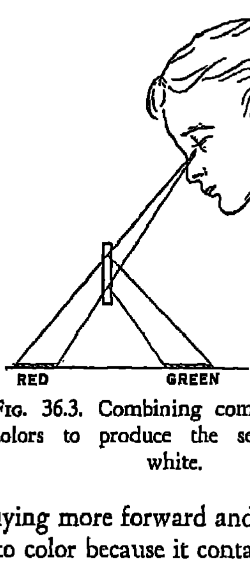


FIG. 36.3. Combining complementary colors to produce the sensation of white.

Retinal areas sensitive to color.—Color sensations are perceived by only a part of the retina. A large portion, namely, that part lying more forward and toward the sides of the globe, is insensitive to color because it contains few or no cones. Images, whatever their colors, falling upon these regions are seen only in black and white. The area of the retina over which blue can be distinguished is larger than that over which either green or red can be seen. The area sensitive to green is smaller again than that sensitive to red and is restricted pretty well to the posterior wall of the globe (Plate VII*b*). The areas of the retina over which these three colors are perceived may be compared to three saucers of differently colored glass, and of graded sizes, placed one inside the other. Light passing through the small green saucer will also pass through the red and the blue saucers. Light striking the area of the retina represented by the green saucer will therefore be sensitive to green, red, and blue. This area supposedly contains all three types of cone. Light passing through the outer band of the red saucer will pass through

the blue as well, but not through the green. The area of the retina represented is therefore sensitive to red and blue only. The rim of the largest—the blue—saucer transmits blue light only, and the retinal area it represents is sensitive only to blue. It possesses presumably only those cones which respond to blue light (Plate VII*c*).

The three qualities of color.—The features of a color by which it can be distinguished from any other color are three—*hue, brilliance,* and *saturation.*

Hue simply means color in the sense in which this latter word is commonly used. Red and green, for instance, are different hues. Hue is determined by the length of the light waves. This quality, therefore, corresponds to the pitch of a sound (p. 379), the spectrum being compared to the scale in music. The hue (or pitch) varies from one end of the spectrum (or scale) to the other. The origins of the names of the fundamental hues can be traced to the language of civilization's infancy. It is of interest to recall that the adjectives red, blue, green, and yellow have been derived from the names of materials and objects having these colors. Thus, red comes from an ancient word for blood. Blue is derived from the color of the sky and from the same root as the verb *to blow*. Green, the characteristic color of young plant life, arose from the word *grow,* and yellow from a primeval word for gold.

Brilliance, or *brightness,* is that quality of a color which depends upon the proportion of blackness mixed with it. For instance, scarlet is brighter than cherry, since it contains less black. Brilliance of a color corresponds to the loudness of a sound. Indeed "loud" is a word often applied to brilliant colors. A sound is loud because the ear is stimulated more strongly by the sound waves. An object has a brilliant color when it absorbs few of the waves of that color and so reflects them in larger proportion to stimulate the retina.

Saturation refers to the proportion of white light with which a color is mixed. If the proportion of white light is high, the saturation of the color is low, and vice versa. Thus pink is a paler—that is, a less saturated—color than red, which gives to the eye a deep rich sensation of color. An object has a color of low saturation when a large proportion of the light which it reflects is white, and only a small proportion of the reflected light has the wave length characteristic of the particular color. The color sensation is rich—

that is, the saturation is high—when a small proportion of the light reflected from the object is white.

Color blindness.—Some persons are blind to red or green or to both colors, and in rare instances to blue. It is thought that the retinas of these persons are lacking in the elements sensitive to these fundamental colors. The condition is usually hereditary and as a rule affects only males—rarely females (p. 47). Occasionally green-blindness results from the excessive use of tobacco. A green object appears grayish to a green-blind person. A person who is red-blind confuses red with green, and he cannot see a red square on a black background. He may choose a bright red tie and think that it is dark green or brown. Any color which contains a mixture of red, such as purple or orange, is perceived by the red-blind as though no red were present. So, to the red-blind person, purple appears a pure blue and orange a yellow. A color mixed with green, such as a greenish-blue or a greenish-yellow, appears a pale blue or yellow to the green-blind.

In certain occupations, such as navigation and railroad operation, color blindness may lead to serious accidents, and for this reason it is of the greatest importance that tests for color vision be made before men are accepted for employment in these occupations. Since about 9 percent of persons are color blind, and so many drive automobiles today, lights of more suitable colors than red and green might be chosen for traffic signals. Red and green, for the same reason, are poor colors to use for license plates. Red letters on a black background would be indistinct to the color blind and even to a normal person at dusk. In semi-darkness we all lose the ability to perceive colors. Red is the first color which we fail to see. In the garden at dusk the poppies and geraniums appear as black blotches, while the corn flowers and delphiniums still retain their blue color. A flower which appears a mauve or bluish pink in daylight is seen as pure blue in the shadows of the evening, for the eye has become insensitive to the red blended with the blue.[1]

Contrast effects.—Most persons have probably noticed that black letters look blacker upon a white than upon a colored background. But it is also true that blue letters look bluer upon a yellow ground

[1] If the reader looks at Plate IV*c* in a dim light, he will find that the blue persists longer than the red.

than upon a ground of any other color, and yellow letters appear a brighter yellow upon a blue ground. Also, green letters look greener against red, and red letters redder against green. Cherries, for example, look brighter against the leaves of the tree than elsewhere. These phenomena are examples of what is termed *simultaneous contrast* (Plate VII*d* C).

If the color pairs mentioned above—blue and yellow, or red and green—were blended together in the form of lights, it would be found that they produced white light.

Any pair of colors which, when fused, produce white are said to be *complementary* to one another.[2] Not only red and green and the other fundamental colors, but every color and shade of color, has some other with which it may be combined to produce white. (See Plate VII*d* B and table on page 350.) There are consequently a large number of complementary colors, and the contrast effect is produced when any such color pairs are placed side by side. Briefly, each color makes its complementary appear more intense. Furthermore, if any two colors which are not complementary to

[2] These facts may be demonstrated very simply by employing a glass plate to blend two complementary colors upon the retina. A green book or other object of this color is placed in front of the person making the experiment. If the green has a bluish tinge, so much the better. A little in front of the green book a red one is placed. A clear glass plate is then held midway between and about 6 inches above the two books, so that the red book can be seen through the glass, and the image of the green book is reflected from the glass's surface (Fig. 36.3). When the two colors fall upon the same part of the retina and are blended, an almost white sensation is produced. Blue and yellow objects looked at in the same way would also produce white.

A top with vertical bands of red and bluish-green, of blue and yellow, or of any two complementary colors, when spun rapidly, appears a uniform dirty white. The separate sensations produced by the complementary colors, when the top is still, become blended in the retina when the top is spinning, since they are repeated in such rapid succession (p. 351). The reader may know by experience, however, that blue and yellow paints, when mixed together, do not give white—far from it, they give a vivid green. A distinction, however, should be drawn between lights and paints. A paint has a certain color because it reflects a certain light and absorbs others. Even the bluest paint is not pure blue; it absorbs all light but blue and a little green. These it reflects. A yellow paint is not pure yellow; it reflects a little green with the yellow. When the two paints are mixed, blue light is absorbed by the yellow paint, and yellow light is absorbed by the blue. So neither of these lights is reflected. On the other hand, green rays, of which a little is reflected by each separate paint, are doubly reflected when the two are mixed. If we could obtain an absolutely pure blue paint and mix it with a pure yellow, rays of all colors would be absorbed, and the result would be not green but black.

each other are placed side by side, each will take on a tint which is the complementary of the other (Plate VII*d* D or E). For instance, if a lemon were placed upon a white surface in bright sunshine, the shadow which it cast would not be a simple dull gray, but a gray tinged with blue—the complementary of yellow. The gray shadow cast by a red object would be tinged with green, or one thrown by a green object with red. The shadows upon the snow in the yellow sunlight are not gray but blue. The artist, by studying these effects and applying them to his work, gives brilliance, life, and beauty to his paintings. He makes a yellow flood of sunshine more dazzling by painting blue into the shadows, which, in turn, are given a depth and an appearance of reality which gray alone could not give.

The list below shows the effects produced by certain colors when they are placed side by side.

(Also see Plate VII*d* B)

Non-complementary Pairs of Colors	Contrast Effect
Red with orange	The red is tinged with greenish-blue (the complementary of orange) and so inclines to purple. The orange is tinged with bluish-green (the complementary of red) and so inclines to yellow.
Yellow with red	The yellow becomes tinged with green (complementary of red), and so inclines to green. The red is tinged with blue and so inclines to purple.
Blue with green	The blue becomes tinged with red (complementary of green), and so inclines to violet. The green is tinged with yellow, and so inclines to yellow-green.
Violet with orange	The violet becomes more blue; the orange becomes more yellow.

Gray becomes tinged with the complementary of any color placed beside it.

Complementary Pairs of Colors	
Red and bluish-green	Both colors become more brilliant.
Orange and greenish-blue	Both colors become more brilliant.
Green and purple	Both colors become more brilliant.
Violet and yellow-green	Both colors become more brilliant.

Simultaneous contrast may be readily seen in Plate VII*d* D and Plate VII*d* E. When the figures are looked at through a tissue paper as it is moved slowly up and down, the gray area on the green ground takes on a faintly red tint (complementary of green), while the gray area on the blue ground appears tinged with yellow (complementary of blue).

If the eyes are directed to a red surface for a short time and then to one colored in the complementary green, the green appears brighter than it would have if the retina had not first been stimulated by red. If these colors were viewed in reverse order—first green and then red—the red would appear more brilliant than usual. This effect is called *successive contrast,* and can be shown for other pairs of complementary colors. Successive contrast is believed to be due to fatigue of the cones of one type (e.g., the red-responsive) and as a consequence the apparently more intense reaction of those sensitive to the complementary color (e.g., the green-responsive).

After-images.—If we look for a while at a bright object, an electric light, for example, and then close our eyes, or direct them to a dark surface, an image of the lighted bulb appears before the eyes. This is called a *positive after-image,* since it has the same appearance as the object seen with the eyes open. Again, if we look for a time at a light or a bright white object and then turn the eyes to a *white* surface such as a blank sheet of white paper, a *black* image in the form of the light or of the object floats before the eyes. This is a *negative after-image.* When the light or object is colored, the after-image is in the complementary color of the original—blue if the original light was yellow, red if the original was green, and vice versa.

A positive after-image is due, it is believed, to the persistence of nervous impulses arising in the retinal cells after the original

stimulus has been removed, much in the same way as, when the skin is struck sharply, pain sensations continue to be felt for a short time afterwards. The sensation in the retina is not instantaneous, like an explosion, but takes time to develop, persists for a measurable length of time, and then fades away. The sensation is more like the striking of a bell with a hammer; the metal continues to vibrate and give out sound for a time afterwards. In motion pictures the effect of movement is, as we know, produced by a

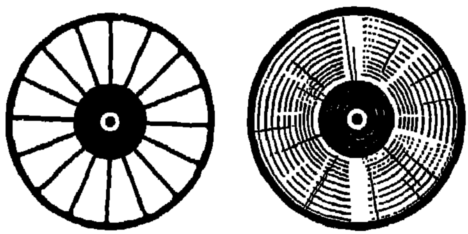


FIG. 36.4. The black spokes of a wheel revolving against a white background appear as a solid gray disk owing to the fusion of the sensations (black and white) upon the retina. A disk marked in alternate segments of different colors would, when rotated, also cause a fusion of the separate color sensations. Thus red and blue would produce a purple, and red and yellow an orange sensation. Complementary color pairs would give a near white.

succession of views showing objects in different positions. The rate at which these different views are shown must be carefully gauged. If the intervals are too short, the impression made by one view upon the retina will not have subsided before the next appears. Blurring is the result. If the interval is too long, the effect produced by one view has ceased some time before the next scene appears. Lack of smoothness and realism is the result. An example of a number of visual impressions overlapping is seen in the effect produced by the spokes of a wheel revolving rapidly (Fig. 36.4). The separate spokes follow one another so quickly that the sensations become fused upon the retina so that the wheel appears solid.

Negative after-images are believed to be caused by fatigue of that part of the retina stimulated by the bright light. If the fatiguing light was white then all three types of cone are fatigued and when a second white image—the blank white surface—falls upon the retina there is no response from the receptors in the previously stimu-

lated area, a sensation of black resulting. When the light is colored, only the cones sensitive to that particular color are fatigued. The subsequent white stimulus (which ordinarily excites all three types of cone) therefore calls forth a response from the other two types of cone alone and an after-image in the complementary color appears.

chapter 37

INTERPRETATION BY THE BRAIN OF IMPULSES RECEIVED FROM THE RETINA

We have seen that the eye is an instrument for the conversion of light energy into nerve impulses. But visual sensations have their seat in the occipital lobe (p. 356)—the cortex of that part of the brain lying at the back of the cranial cavity. Destruction of this part of the brain on both sides in man will cause blindness just as

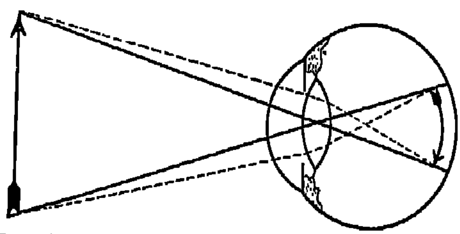


FIG. 37.1. Inversion of the image upon the retina.

complete as if both eyes were destroyed. This region of consciousness interprets the messages received from the retina.

The position of the retinal image.—In a camera, the image thrown by the lens upon the film or plate is upside down and reversed from side to side. Images are cast upon the retina in a similar way (Fig. 37.1). Yet we do not see things upside down, or as mirror images. Things are really as they seem. Through experience the brain has learned to interpret correctly the pictures cast upon the retina, so that we see objects in their true positions. This fact may be demonstrated by the reader upon himself. If he closes his eyes and presses upon the outer side of one eyeball so as to stimulate the retina, he will perceive a ring of light. The bright figure, however, does not

appear to be in the region of the finger, but on the opposite side of the eye. Similarly, if the lower part of the globe is pressed, the ring of light appears to be above the eye. This simple experiment shows that the brain interprets impressions received from the outer or upper parts of the retina as being opposite the inner or lower parts, and vice versa. The brain, by long experience, has come to know that the inverted and reversed images which outside objects cast upon the retina do not represent these objects in their true positions, and without any conscious effort turns them upright.

Binocular vision.—It must also be remembered that an image is formed upon *each* retina. Our vision for this reason is called *binocular*. Yet only one image is seen so long as both eyes are maintained in their correct positions by the eye muscles. If one eye, however, is pressed gently to one side by the finger so that the direction of its sight is not correctly related to that of the other eye, two images at once appear, one beside the other. The reason that, normally, only one image is perceived, though two are formed—one in each eye—may be understood from Figure 37.2. Normally, each of the two images formed by any object falls upon one half of each retina; but, as a result of the crossing and rearrangement of the optic nerve fibers behind the eyes, the two images are recorded on only one side of the brain. Thus, an object placed before our eyes throws an image upon the left halves of both retinas, or upon the right halves of both retinas, but never, so long as the eyes are in their true positions, upon the right half of one retina and upon the left half of the other. It would appear that any point on the half of one retina is paired with a point in the same relative position on the corresponding half of the opposite retina. Thus we may think of a single visual receptor in the left half of the left retina being paired with one in the left half of the right retina. Rods and cones in the right halves of the retinas would be coupled in a similar way. The impulses set up by the stimulation of these paired receptors eventually take the same path to the occipital cortex of one side of the brain and probably have their destination in a single nerve cell or a small group of nerve cells. This is known as the *theory of corresponding points,* advanced to account for the fusion of the separate retinal images. Figure 37.2 shows the fibers from the left halves of the retinas going to the left side of the brain, and those from the right halves going to the right side of the brain. The

result is that a single impression is registered in consciousness. When the eyes are "out of line," the two images fall upon non-corresponding points in the retinal halves, and the impulses pass to both sides of the brain. As mentioned above, double vision (*diplopia*) then results.

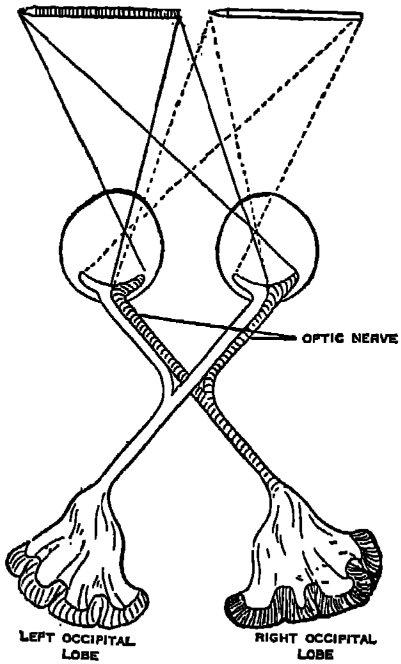


FIG. 37.2. Diagram to show the course of impulses from retina to occipital lobe. The unbroken lines indicate the course of light rays from an object toward the left. The dotted lines indicate light coming from an object toward the right.

Severe damage to the optic nerve of one side causes blindness of the nerve of that side (Fig. 37.2). But if the pathway has been injured after the fibers have crossed, or if the occipital region of only one side is destroyed, the blindness is confined to the halves of the retinas from which impulses are received. This is called *hemianopia* (literally, half-blindness).

Stereoscopic vision.—The impression of distance and the solid substantial appearance of surrounding objects are also dependent upon processes having their seat in the brain. Our surroundings are not flat, like a photographic scene; everything about us stands out clearly from its background. Objects appear to have depth and

volume, as well as width and height. Our vision is three-dimensional or *stereoscopic*. The stereoscopic effect is due chiefly to the fusion of the two retinal images, which are not precisely the same. If a cubical object, placed directly in front of the reader, is viewed with one eye (the other one being closed), and then with the other alone, it will be found that the image formed by the right eye is very slightly different from that formed by the left (Fig. 37.3).

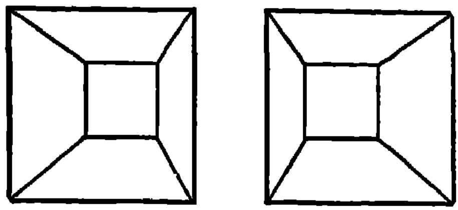
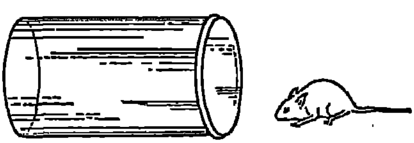


FIG. 37.3. Stereoscopic effect caused by the fusion of slightly dissimilar images. Hold the figure about six inches from the eyes and "stare through it." The images will become fused and produce an effect of solidity and depth in the drawing.

The right eye is in a position to see more of the right side of the object and the left eye to see more of the left side. The brain blends the two dissimilar images into one; but just as, when two colors are mixed together, the resulting single color has some of the original two in its make-up, so the single fused image has hidden in it the slight differences of the two of which it is composed. It is this hidden difference which is largely responsible for objects stand-

FIG. 37.4. Fusion of dissimilar images. When the figure is held about six inches from the eyes and gazed at steadily, the mouse enters the glass vessel.



ing out in relief with the appearance of solidity. A photograph or picture appears flat, because the images in the two eyes are identical, and their fusion by the brain produces no stereoscopic effect. Even images which are quite unlike may be fused (Fig. 37.4).

The ordinary stereoscope makes use of these principles. A camera with two lenses, set, like the eyes, a short distance apart, takes two views. The photographs are slightly different, since the angles at

which they are taken are different. When viewed through the stereoscope, the pictures are directed one to each eye by means of special lenses. The brain fuses the images to produce a remarkable effect of depth and solidity.[1]

The judgment of size.—Our appreciation of the size of any object depends upon the size of the image which the object casts upon the retina. But the size of the retinal image is dependent not only upon the actual dimensions of the object itself but also upon the distance of the object from the eye. For instance, a church steeple a mile away throws an image upon the retina which is no larger—perhaps smaller—than the image cast by a needle a foot in front of the eyes. Yet we know that the steeple is immensely larger than the needle. The brain has estimated the difference in the distances of the steeple and the needle, and has made allowances in judging the size of the two objects. This sense of distance is caused to a large extent by impulses which pass from the muscles within the eyeball (ciliary muscles), when they contract or relax to accommodate the eye for near or distant objects (p. 359). For similar reasons the moon when rising above the horizon appears to be twice or three times the size that it does when high in the sky. The image which it forms upon the retina is, however, of the same size in both positions. It is our estimate of the distance which is at fault. When we look at the moon over the land the distance appears to be greater than when we look at it overhead. Consequently, since our judgment of an object's size from the size of its retinal image

[1] A very ingenious but simple stereoscope involving the same principle is one in which two slightly dissimilar pictures, one in blue and the other in red, are printed, one overlapping the other. When looked at with the unaided eyes, the pictures are no more than a confused jumble with a red-blue outline. If, however, they are looked at through a pair of spectacles with a red glass on one side and a blue glass on the other, a remarkable stereoscopic effect is produced. The colored spectacles sort out the confused pictures and send one to each eye. The red picture is seen as black through the blue glass, since this absorbs the red rays; the blue picture is indistinct. The blue picture is seen as black through the red glass, since the blue rays are absorbed; the red picture is indistinct. So, the separate and slightly dissimilar images fall upon opposite retinas. The resulting sensation is a scene in black and white, conveying the impression of depth and solidity. The stereoscope may be used for the detection of counterfeit notes. The suspected note is placed beside a genuine one. If one note is a copy of the other, and not made from the same plate, it will inevitably differ in detail from the genuine, no matter how skillfully the work has been done, and the dissimilar images will give an appearance of depth in certain parts of the design which otherwise would not appear.

is influenced by our estimation of its distance from us, the rising moon appears much larger (Fig. 37.5).

We have all experienced the effect that is produced when, while our eyes are accommodated for a *distant* scene, a minute near object, such as a speck of dust, comes suddenly into view: the tiny object appears to be of huge proportions. The same effect is produced by after-images (p. 351). If a small bright object, placed close to the eyes, is looked at steadily for a time and then the eyes are directed to a blank wall some distance away, the after-image seems immensely larger than the object itself. The accommodation of our eyes to the more distant wall deceives the brain, for the nerve impulses which it receives from the muscles of accommodation leads it to believe that the after-image comes from a distant object; it consequently seems larger.

Judgment of distance.—Not only does our appreciation of distance influence our judgment of size, but also our general knowledge of the size of objects of certain shapes influences our judgment of distance. For example, we know from previous experience that a steeple is much larger than a needle; therefore, if the retinal image of the steeple is no larger than that of the needle at a short distance, the former is judged to be much farther away. The relation of an object to other objects in front of and behind it, the stereoscopic effect of depth, and the effects of accommodation already referred to, all aid us in our appreciation of distance as well as of size. The air is not perfectly transparent; hence, when a distant view is seen it appears dimmer and takes on a bluish tint. For this reason visitors to climates where the air is unusually clear make mistakes in judging distances. Objects appear closer than they really are. A hazy day makes scenes appear more distant.

Optical illusions.—The brain is sometimes deceived by imitations of certain effects upon which it bases its judgment of the size, shape, and color of objects in the outside world. Errors of judgment caused in this way are called optical illusions. The effect produced by the stereoscope (p. 357) and the misjudgment of size and distance (p. 358) have already been referred to. The illusions of distance caused by blue and of nearness by red and yellow are discussed on page 364. Other examples of optical illusions are shown in Figures 37.5-37.10.

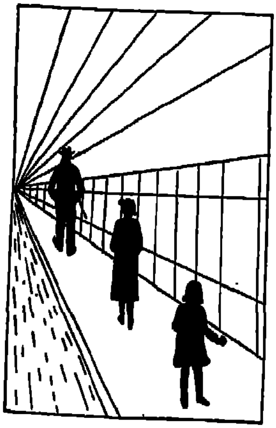


FIG. 37.5. Illusion of size. The figure of the man is actually smaller than that of the child, but the effect of distance produced by the converging lines causes it to appear larger.

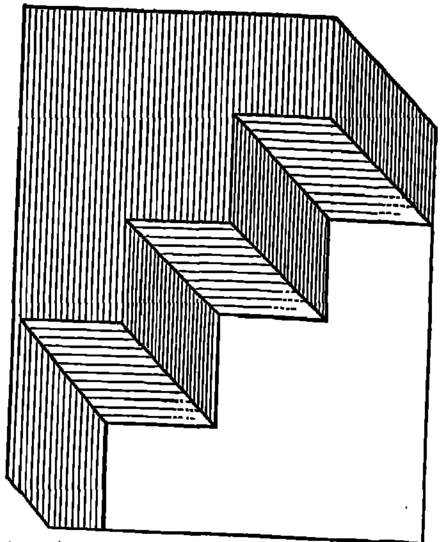


FIG. 37.7. The figure shows a series of steps which, when gazed at fixedly, appear as an overhanging wall. (*After Bernstein.*)

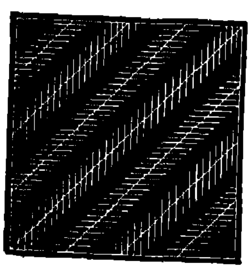


FIG. 37.6. Zollner's lines. The long diagonal lines are parallel, though they appear otherwise.

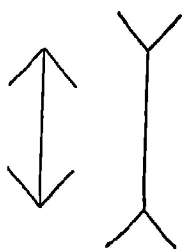


FIG. 37.8. Illusion of size. The vertical lines are both of the same length.

FIG. 37.9. Illusion of distance. The distance from *A* to *B* appears to be greater than that from *B* to *C*. They are both the same.

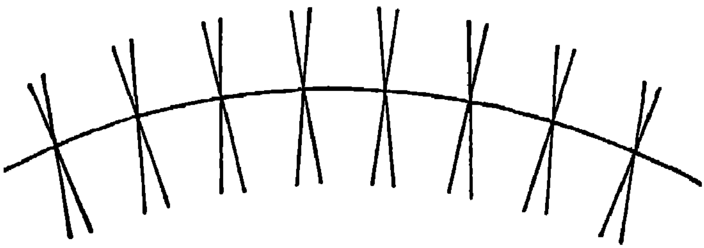


Fig. 37.10. Hold the page in a horizontal position a little below the level of the eyes and about eight inches in front of the face. Look steadily at the curved line. A series of short vertical bars appear to pierce the paper. When the page is moved slowly from side to side, the bars appear to sway to and fro. (*Franklin after Howell.*)

Movements of the eyeballs.—Each eye is furnished with six small muscles, which are attached by their outer ends to the circumference of the eye globe near its equator, and by their inner ends to the bony walls of the eye socket. One muscle (*external rectus*), attached to the outer side of the eye, turns the eye outward; another (*internal rectus*), on the inner side, rotates it inward. The eye is turned upward by a muscle (*superior rectus*) fixed to the upper part of its circumference; its rotation downward is effected by a corresponding muscle (*inferior rectus*) attached below. The remaining two muscles are directed obliquely, to be attached one to the upper and outer segment of the globe, the other to the lower and inner segment. The first mentioned of these oblique muscles (*superior oblique*) rotates the eyeball downward and outward; the other (*inferior oblique*) rotates it upward and outward toward the temple. Normally, the muscles of both eyes act in unison, so that the positions of the eyeballs are always kept in their proper relation to each other. When a muscle of one eye pulls more strongly than the corresponding muscle of the other eye, the lines of sight of the two eyes are not correctly directed. The person is said to be cross-eyed. The technical term for this condition is *strabismus*. Under these circumstances the images fall in different regions of the two retinas (p. 355), and it might be thought that such a person would suffer from double vision, but, as a matter of fact, he usually learns subconsciously to disregard the image in one eye.

chapter 38

OPTICAL DEFECTS

Two defects, *spherical* and *chromatic aberration,* are possessed by all ordinary convex lenses.

Spherical aberration.—Rays of light passing through a simple convex lens are not all brought to a focus at one point. The rays

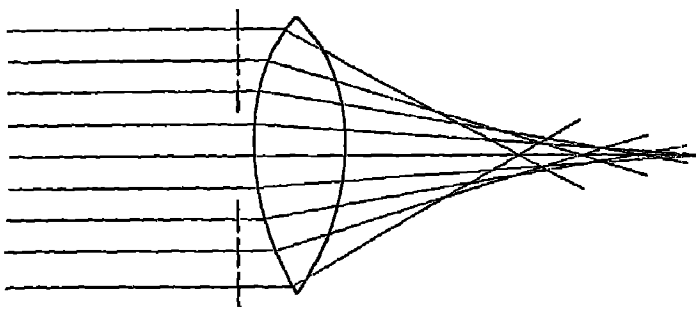


FIG. 38.1. Spherical aberration. Note that the outer rays come to a focus in front of the more central rays. The vertical broken lines in front of the lens show how a "stop" of a camera or the iris of the eye cuts off the outer rays.

passing through the lens near its circumference are bent (refracted) more strongly than the rays transmitted nearer its center. The result is that the rays passing through the outer part of the lens cross those passing more centrally (Fig. 38.1). This defect of lenses is called *spherical aberration.* In the manufacture of expensive camera lenses special means are employed to correct the defect. Such lenses are made in several parts, cemented together. The central part of the lens is composed of a glass which refracts the light rays more in accordance with the refraction of the outer part. All rays, whether they pass through such a lens near its circumference or near its

center, meet at the same point. On the other hand, clear images may be formed with a cheap lens if the outer interfering rays are cut off by means of a diaphragm. For this reason, as we all know, the sharpest photograph can be taken when the small "stop" is used, and the rays of light are thereby restricted to the center of the lens. These devices, resorted to by the manufacturers of lenses for the correction of spherical aberration, are an imitation of the methods employed by nature to perfect the organ of sight. The central portion of the crystalline lens is composed of a material slightly

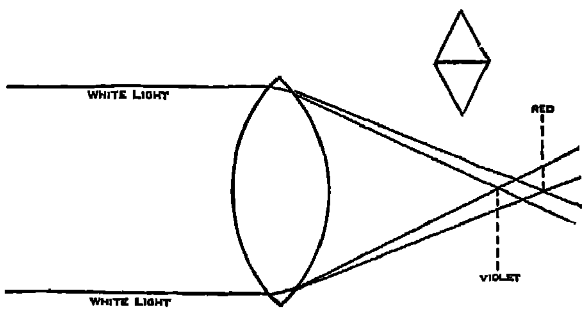


FIG. 38.2. Illustrating chromatic aberration. The small figure shows how a simple lens is essentially two prisms placed base to base.

different from that composing the outer part, with the result that the outer and inner rays are refracted to nearly the same degree. The iris, also, like the camera's diaphragm, cuts off any outer interfering rays.

Chromatic aberration.—The waves of different lengths which compose white light are not all refracted to the same degree by an ordinary simple lens (Fig. 38.2). When one attempts to focus the rays of light from the sun by means of a cheap convex lens, it is impossible to get a clear white light. A halo or fringe of colors—red, orange, yellow, green, and blue—appears. The ring of spectral colors is caused by the glass prisms of which the lens is composed [1] refracting the light rays to different degrees according to their wave lengths. The red rays are refracted less strongly than are the orange, the orange less than the yellow or green, and the green less than

[1] A simple biconvex lens is in reality two glass prisms placed base to base. The splitting of white light by a prism has been described on page 344. A simple concave lens resembles two prisms placed apex to apex.

the blue. Thus the colors are separated and laid out in bands as in a rainbow. Chromatic aberration (Gk. *chromos* = color) is corrected in camera and microscope lenses by cementing a biconvex lens of crown glass to a concave block of flint glass (Fig. 38.3). A lens made in this way is called *achromatic,* that is, non-color-forming. The lens of the eye is not corrected for chromatic aberration; yet we do not see objects surrounded by colored halos. The reason that we do not is that, in looking at colored objects, the eye alternates its focus rapidly for the different colors. At one instant the refractory power is slightly increased, at another slightly diminished. At one instant red is in focus, at another instant blue or green. The different color impressions occur so rapidly that they become fused in the retina to produce the sensation of white (p. 344). The adjustments of the lens are so slight and made with such little effort that we are unconscious of them.

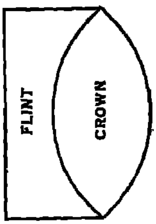


FIG. 38.3. The structure of an achromatic lens.

These facts are used by the artist to produce the illusion of distance in his pictures. Our judgments of distance are made, to a large extent, upon the efforts of accommodation which we make practically unconsciously (p. 337). For instance, when we look at a distant object, the suspensory ligament is taut, and the ciliary muscles are relaxed. When the eyes are focused upon a near object, the suspensory ligament is relaxed, and the ciliary muscles are contracted. The brain receives nerve impulses from these structures, and, through long experience, has learned to judge the distance of an object by the changes in accommodation required to see it clearly. When the artist, therefore, paints a distant hill in blue or violet, the eye must, in order to bring the blue color into focus, counteract the greater bending of the blue rays. Its lens is therefore put into the shape in which its power is least (p. 341), that is, as though the eye were focused upon a far object. The brain is deceived to a certain extent, and an impression of distance is created. Yellows and reds, when included in a picture, produce the reverse impressions. They seem to bring objects closer. Yellow and red rays are bent less strongly; therefore, in order to bring these colors into focus, the crystalline lens must increase its power, just as though the eye were viewing a near object. These facts may be clearly demonstrated by placing a red and a blue lantern side

by side. Though both lights are exactly the same distance from the eye, the blue one appears to be behind the red. Chromatic aberration is more pronounced toward the circumference of a lens; hence the iris, to a certain extent, by covering this part of the lens, diminishes this defect of the eye.

Presbyopia.—This is a defect of the eye, already mentioned on page 341, in which the lens, having lost the resilience or elasticity of youth, is unable to increase its power sufficiently to focus images of near objects upon the retina.

Defects of Vision Due to Abnormal Shapes of the Eyeball

The three defects described above may be considered natural or physiological. The first two are present in all eyes. The third occurs as a natural consequence of age. The three defects to be described in the following paragraphs are present in some eyes only and are due usually to imperfections at birth. The normal eye, as mentioned elsewhere, is nearly spherical. The vertical and transverse diameters are almost the same and only 1/25 inch shorter than the diameter from front to back. In other words, the eyeball is normally very slightly longer than it is broad and high. A normally proportioned eye is called *emmetropic.* Sometimes, however, the eye is considerably longer than it is broad. A person with such an eye is nearsighted, and the condition is called *myopia.* On the other hand, the eye may be shorter than it is broad; this condition is known as *hyperopia* (Fig. 38.4). Again, the cornea or the lens or both may be distorted, and the condition known as *astigmatism* is produced.

Myopia or nearsightedness.—In this condition the crystalline lens refracts the rays of light to the same degree as in a normal eye, but, since the diameter of the eyeball from front to back is too great, the retina is a little beyond the point where the rays come to a focus. In other words, the lens is too strong for the length of the eyeball. After the rays come to a focus in front of the retina, they cross again and, upon reaching the retina, form a blurred image. It is just as though the film or plate of a camera were moved backward from the point where the rays entering through its lens would come to a focus and form a clear image. There is only one way in which the defect of nearsightedness may be overcome—by

making the rays of light more radiating (divergent) before they enter the eye, so that the crystalline lens will be just strong enough to bring them to a focus upon the retina. The myopic person is therefore fitted with concave lenses, which diverge the rays, and so partly counteract the converging action of the crystalline lens (Fig. 38.4). The myopic person without glasses corrects the defect by bringing the book or other objects at which he is looking closer

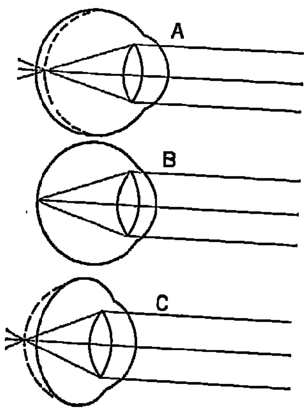


Fig. 38.4. Defects of vision due to abnormalities in length of the eyeball as compared with the normal. *A*, myopia; *B*, emmetropia (normal); *C*, hyperopia (or hypermetropia).

to the eyes, since the closer the object is, the more divergent are the rays which reach the eye from its surface.

Hyperopia or farsightedness.—In this condition the diameter of the eye from front to back is too short. The crystalline lens is unable to converge the rays sufficiently to bring them to a focus upon the retina. The hyperopic person, to examine an object, holds it at arm's length, for then the rays are less divergent. Convex lenses are employed to aid the crystalline lens.

Astigmatism.—This is probably the commonest of all defects of the eye. Indeed, practically all eyes possess it to a greater or less extent, but it is only when the condition is extreme that vision is impaired. The word itself means "without point" (Gk. *a* = not; *stigma* = a point). That is, rays of light are not brought to sharp points upon the retina but form, instead, short lines. The stars, for instance, should appear as small bright dots; but, as a result of the slight astigmatism of even the best of eyes, they seem to have short lines radiating from their centers; hence the expression "star-

shaped." The constant rapid movements of our eyes cause the lines to shift slightly upon the retina, and the stars appear to twinkle. A light in darkness, for similar reasons, seems to emit radiating beams.

In order that rays coming from some point in the outside world shall all converge and come to a point upon the retina, they must

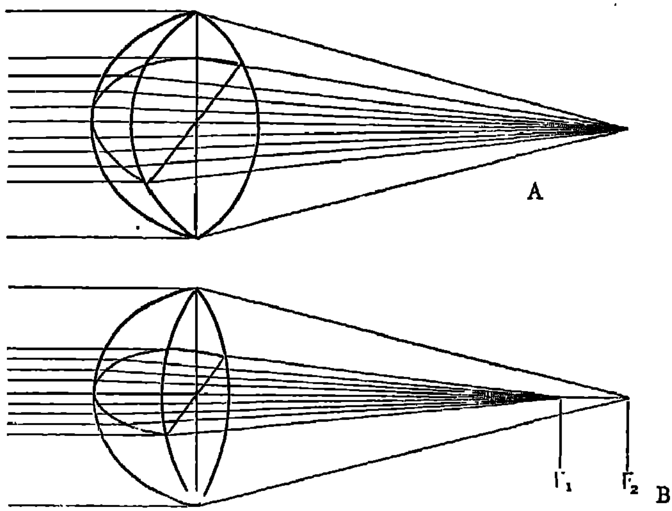


FIG. 38.5. In *A* the horizontal curvature of the lens is the same as the vertical; rays of light passing through the horizontal and vertical diameters are in consequence focused to the same point. In *B* the horizontal curvature is greater than the vertical. The rays passing through the horizontal diameter are focused at F_1 and those passing through the vertical diameter at F_2.

all be converged to precisely the same degree. They must all stream together, like water in a funnel, toward a single point. If we should place a lens in the wall of a dark and dusty room and allow the sunlight to stream through, we would see, not a flat pennant-like beam of light, but one that was cone or funnel shaped.

The rays passing through all diameters of a perfect lens come to a single point or focus. If, on the other hand, the curvature along one diameter (meridian) is greater than along another, the rays passing through the former will be bent more sharply and come to a focus at a shorter distance behind the lens than those passing through the latter.

We know that a flaw in a lens, a raised area here, or a depressed area there, will cause distortions of the images which it forms. Rays passing through a meridian having the raised or depressed region will not, of course, be bent to precisely the same extent as rays passing through elsewhere. When such blemishes exist, the rays passing through different diameters of the cornea or lens will not meet at one point, as they should to form a clear-cut image (Fig. 38.5). Astigmatism is due to just such unevenness in the surface of the cornea or of the lens, a person with this defect being unable to focus perfectly the rays passing through the lens in all its diameters. Looking at the face of a clock, for example, the vertical numerals XII and VI may be clear, but the horizontal IX and III may be blurred, or vice versa. Again, the diagonal numerals may be out of focus, while the vertical and horizontal are clear. The person suffering from astigmatism wears glasses with the convexity of the lens increased or reduced, as the case may be, in certain diameters (meridians) to counteract the defects in corresponding diameters of the eye.

chapter 39

THE PHYSIOLOGY OF HEARING. THE SEMICIRCULAR CANALS

The Structure of the Ear

The ear consists of three distinct compartments or regions, each of which has its own special part to play in the mechanism of hearing. These regions are termed the *outer* (*external*), *middle,* and *inner* (*internal*) ears (Fig. 39.1).

The outer (external) ear.—The outer ear consists of (1) the irregularly shaped but roughly semicircular shell of skin and cartilage projecting from the side of the head, called the *pinna* or *auricle* and (2) a short funnel-shaped canal called the *external auditory meatus.* The auditory meatus is somewhat tortuous and tunnels the bone of the skull; it is lined with skin. Its inner end is blind, being closed by a thin membrane covered with delicate skin and known as the *tympanic or drum membrane.* This membrane forms a flexible partition between the outer and middle ears and forms a part of the outer wall of the latter chamber.

The middle ear, or tympanum.—The middle ear lies on the inner side of the tympanic membrane. It is a small chamber hollowed out of the skull bone. All its walls, therefore, are composed of bone except the outer one, which is partially formed by the tympanic membrane. A chain of three miniature bones or *ossicles* is slung from the drum membrane to the inner wall of the middle ear. The outermost ossicle is shaped like a hammer or club, and is therefore called the *malleus,* the Latin word for hammer. It is attached firmly by its handle to the drum membrane. The middle bone looks something like a tiny bicuspid tooth. It was thought by some

to resemble an anvil and so was named the *incus*. The innermost bone is not unlike a stirrup, and is therefore known as the *stapes* (Fig. 39.2). The footplate of the stirrup-like bone fits snugly into a small *oval window* placed in the inner wall of the middle ear. This

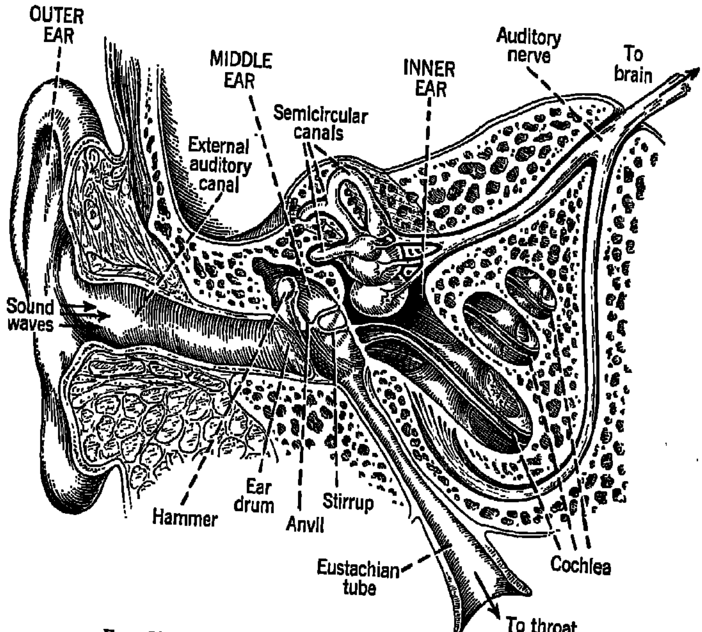


FIG. 39.1. Section through the ear to show its parts.

window opens into the inner ear. Situated a little lower in the inner wall is a second window—the *round window*. It is closed by a thin membrane (p. 377). In the frog's ear a single bar of bone stretches from the drum membrane to the inner ear. Fish, so far as can be learned from experiments in which firearms have been fired near them, possess no sense of hearing.

The longest of the ossicles (the malleus) is only about a third of an inch long (8-9 mm.); the incus and stapes are about 7 and 4 mm., respectively, in their longest diameters.

No doubt the reader has noticed the cords which run down the side of a bandsman's drum, by which the parchment can be stretched. The tympanic membrane is also furnished with the

means for making it tighter for the perception of high-pitched sounds. A tiny muscle called the *tensor tympani* (drum stretcher), which runs from the wall of the tympanum to the malleus, serves this purpose (Fig. 39.2). This muscle also fulfills a protective function against loud sounds, serving to prevent a too violent movement of the tympanic membrane. A second muscle, called the *stapedius*, stretches from the wall of the tympanum to the stapes. It prevents the footplate of the stapes from being driven too forcibly into the oval window.

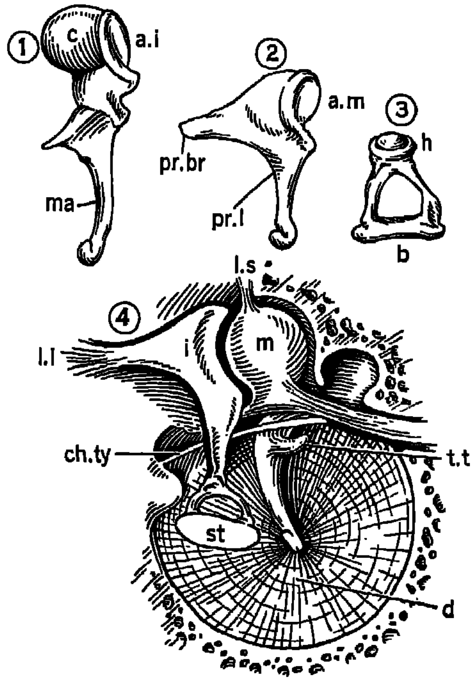


FIG. 39.2. The auditory ossicles. 1, left malleus viewed from outer side (Helmholtz): *c*, head; *a.i*, articular surface for incus; *ma*, handle. 2, left incus: *pr.br*, short process; *pr.l*, long process which articulates with stapes; *a.m*, articular surface for malleus. 3, left stapes: *h*, head; *b*, base or "footplate." 4, the middle ear viewed from the inner aspect and showing ossicles in position: *d*, drum membrane; *i*, incus; *m*, malleus; *st*, stapes; *ch.ty*, chorda tympani nerve; *l.s*, ligament of malleus; *l.i*, ligament of incus; *t.t*, tendon of tensor tympani muscle.

A small tube—the *Eustachian tube*—runs from the middle ear to the back of the nose (Fig. 39.1). By means of this passage, air can pass into or out of the middle ear. The importance of the Eustachian tube will be explained later.

The inner (internal) ear.—The inner ear contains the essential organ of hearing. Just as the retina is the essential organ of sight, wherein light energy is converted into nervous impulses, so in the

inner ear are found those receptors (p. 275) which are especially designed for the conversion of sound vibrations into nerve impulses. The impulses, upon reaching the brain, give rise to the sensations of sound. The globe, lens, iris, etc., of the eye serve merely to trans-

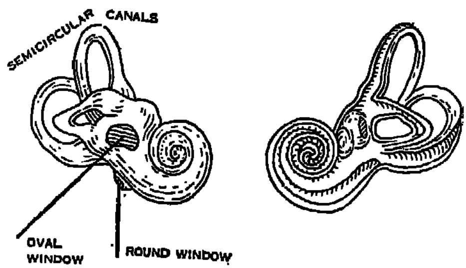


FIG. 39.3. The cochlea and semicircular canals. In the right-hand figure the cochlea and semicircular canals have been sectioned to show their interiors.

mit, focus, and adjust the rays of light so that they will act to the best advantage in stimulating the special elements of the retina. So, too, the outer and middle ears serve only to convey sound vibrations to the receptors of hearing situated in the inner ear. This special organ of hearing is contained in a spiral-shaped chamber

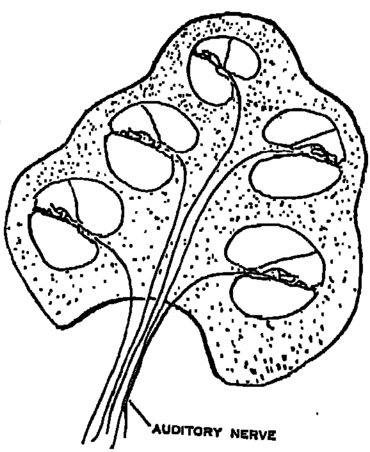


FIG. 39.4. A vertical section through the cochlea showing the three canals or stairways (diagrammatic).

or passage tunneled out of the skull bone. Since the spiral chamber resembles nothing so much as a snail's shell, it has been called the *cochlea* (Figs. 39.1, 39.3, and 39.4). The spiral makes 2½ turns. Within this twisted bony canal is a tube of membrane, which

follows the turns of the tunnel in the bone and fits it almost as closely as the inner tube fits a tire. This membranous tube, however, has not a simple single cavity, for two membranous partitions divide the interior of the coiled chamber lengthwise into three. All

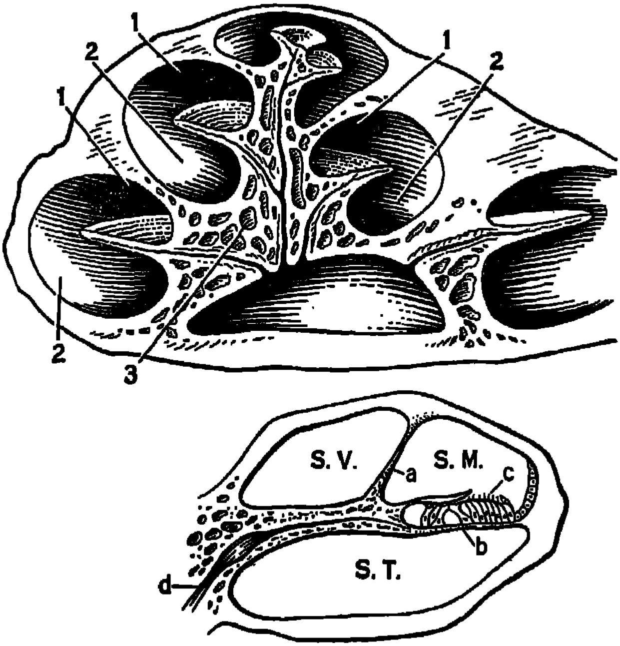


FIG. 39.5. *Upper drawing,* a view of the osseous cochlea divided through the middle. (*After Arnold.*) 1, scala vestibuli; 2, scala tympani; 3, modiolus, showing tunnels transmitting branches of auditory nerve. *Lower drawing,* enlarged sketch of one turn of the cochlea (*redrawn after Quain*). *S.V.*, scala vestibuli; *S.M.*, scala media (cochlear duct); *S.T.*, scala tympani; *a,* Reissner's membrane; *b,* basilar membrane; *c,* organ of Corti; *d,* auditory nerve.

three chambers are filled with fluid. Since the interior of the cochlea suggests a spiral staircase, each of its membranous passages has been called a stairway or *scala* (Fig. 39.5). So we have (1) the stairway of the vestibule (*scala vestibuli*), (2) the middle stairway (*scala media*), (3) the stairway of the tympanum (*scala tympani*).

The scala vestibuli communicates with the middle ear through the oval window which, as mentioned above, holds the footplate of

the stapes. The membrane stretched across the round window separates the scala tympani from the middle ear.

The delicate membranous partition separating the scala media from the scala tympani is called the *basilar membrane*. Upon it rest the sensitive nerve cells (receptors) and the nerve fibers essential for hearing. This collection of cells is known as the *organ of Corti* (Figs. 39.4, 39.5, and 39.6). The cells are long and narrow and stand upright side by side. Some are capped by a row of hairlike processes and are therefore called *hair cells*.

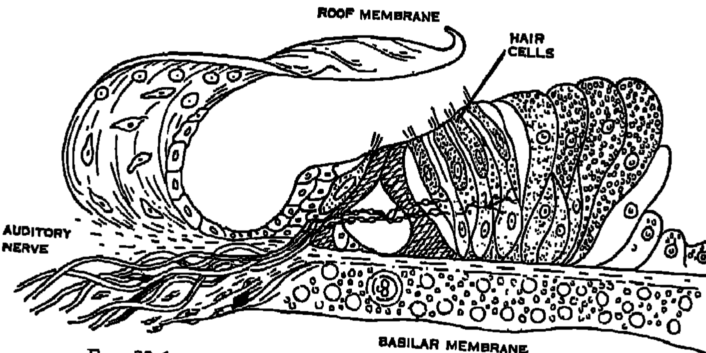


FIG. 39.6. Microscopic appearance of the organ of Corti.

Overlying the hairs is a very delicate membrane—a mere wisp of tissue—which is fastened by one end, but, like a tag of seaweed clinging to a rock, has its other end free to move with every movement or vibration in the fluid in which it floats. It is called the *roof* or *tectorial membrane*.

The nerve of hearing—*auditory* or *acoustic nerve*—enters the central bony column of the cochlea and breaks up into branches which pass along the basilar membrane. Each hair cell receives a very fine nerve twig.

It is somewnat difficult to visualize the complicated structure of the cochlea, with its three spiral stairways, and the manner in which these communicate through the oval and round windows with the middle ear. For the sake of simplicity, the three membranous compartments may be unwound and shown in a straight line side by side, as drawn diagrammatically in Figure 39.7.

The Sense of Hearing

The structure of the ear—outer, middle, and inner—having been sketched, we are in a position to understand how sound waves, sent out by a vibrating body and reaching the ear through the air, are converted into those sensations which we know and speak of as music, noise, and sounds of various kinds.

A few words must first be said concerning the physical nature of sound. Every sound which we hear is due to waves of air beating

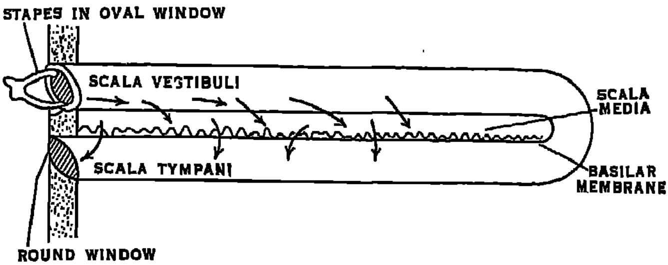


Fig. 39.7. Diagram of the passages of the cochlea straightened out to show the manner in which vibrations are transmitted from the oval to the round window through the scala media. The wavy line represents the organ of Corti.

upon our ears. The type of sound, its pitch, its loudness or its softness, its sweetness or its harshness, depends upon the *frequency, size,* and *form* of the air waves. Sound waves are transmitted through the air at a speed of about 1,100 feet per second. As compared with the speed of light, this, of course, is but a snail's pace. That is why we see the puff of a steam whistle a mile away long before we hear it. The waves of sound, however, may be long, and only a few may reach the ear during each second. Or they may be very short, and then thousands may strike the ear in the same time. When the waves are long and at a rate of only a few per second, we hear a deep booming or rumbling sound. When the waves are smaller and beat in more rapid succession upon our ears, the sound has a higher pitch. When a body such as a bell, a gong, or a tuning fork is struck, or a violin string is twanged, all the tiny particles of the object's substance are set into vibration. The vibrations are transmitted in all directions as a series of compres-

sion waves—that is, alternating compressions and rarefactions (or expansions) of the surrounding air. These motions of the air are called *sound waves, double vibrations*, or *cycles* (Fig. 39.8).

Not all waves in the air cause a sensation of sound. Unless their frequency is within a certain range, nothing is heard. For example, waves are set up when a stick is moved slowly through the air but they are too large and infrequent to make any impression upon our ears. But if the stick is swished rapidly through the air, the wood itself vibrates, smaller and more rapidly repeated waves are formed, and a sound is heard. On the other hand, we know that

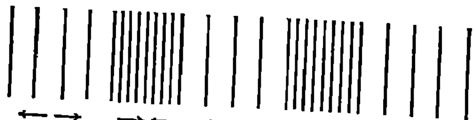


FIG. 39.8. Diagrammatic representation of sound waves. The groups of lines separated by narrow spaces represent the compression phases of a wave; the more separated lines represent the phases of expansion or rarefaction. The arrows indicate the direction of movement of the air particles.

some animals, bats, and some insects have means (larynx, wings, etc.) for causing very rapid waves in the air which our ears are not sensitive enough to hear. The human ear does not register sound waves which are of very low or extremely high frequency. If the double vibrations are fewer than 16 per second or more than 30,000 per second, no sound is heard by the human ear. Cats are said to be able to detect sound waves at a higher rate than this; they can probably hear the high-pitched sounds made by a mouse, which are usually quite inaudible to human ears. The various musical instruments produce sound waves which range from 30 to 4,000 cycles per second. The vibrations of the ordinary human voice range from about 90 to 800 cycles per second. Some famous bass singers can go as low as 50 cycles per second, and sopranos as high as 1,500 per second or even higher.

The sound waves are caught by the pinna or auricle and directed down the funnel-shaped auditory meatus. The pinna is set so that it looks a little forward to catch sound waves coming from the front. But man cannot turn his ears in the direction of a sound without turning his head as well. Animals, however, have special muscles which move the ears. We have all seen dogs and horses

"prick up their ears" and turn them to catch the sound waves coming from a certain direction. Though man has similar muscles, they are weak relics and of no use for this purpose.

The sound waves reaching the bottom of the auditory meatus set the drum membrane into vibration. The membrane beats in time with the air waves. The vibrations are carried across the middle ear by the small chain of small bones to the oval window in the bony partition separating the middle and inner ears. We have seen that the footplate of the stapes fits into the oval window. This window, in turn, communicates with the fluid in the cochlea. Thus the vibrations of the tympanic membrane are transmitted to the inner ear, where the receptors of hearing are situated. The three ossicles of the middle ear of man and higher animals are joined together in such a way that they act as a lever which magnifies the movements of the drum membrane and thus increases the force exerted upon the footplate of the stapes in the oval window. Furthermore, since the area of the tympanic membrane is much greater than that of the oval window, the force of the sound waves is concentrated at the latter point.

As we have already noted (p. 374), the scala vestibuli is separated from the scala media by a thin membranous partition. It is easy then to understand that vibrations set up in the fluid of the scala vestibuli will be transmitted to the scala media and thence to the scala tympani (Fig. 39.7). It follows, therefore, that the basilar membrane, which forms the partition between the scala media and scala tympani, will vibrate in unison with the tympanic membrane. The hair cells of the organ of Corti, lying upon the basilar membrane, will be driven swiftly with each double vibration against the tectorial membrane, which floats above them. Thus a series of taps is applied to the processes of the hair cells which serve as mechanical stimuli to the terminals of the acoustic nerve.[1] Nerve impulses are in this way transmitted to the center for hearing in the cortex.

The round window of the middle ear.—The round window, which lies in the bony partition between the inner and middle chambers of the ear, is closed by a thin flexible membrane, which

[1] It may be, as some believe, that the hairs of the hair cells are not separated from the roof membrane but are actually attached to it. If this is so, a succession of pulls upon the hairs, rather than a series of taps, provides the stimulus when the basilar membrane vibrates up and down.

alone separates the scala tympani of the cochlea from the middle ear. The window, with its membranous covering, is for the purpose of allowing the fluid in the scala tympani to make an outward movement when the footplate of the stapes moves inward, and an inward movement when the footplate moves outward. Fluids, as you know, cannot be compressed; therefore, if there were no round window, the footplate of the stirrup could not make any movement, nor could any movement be transmitted to the fluid within the cochlea. The fluid would be bottled up in unyielding bone, and the sensitive hair cells immersed in it could not be moved by any force applied to the stapes. If a bottle is filled to the top with water, it is a foregone conclusion that the cork cannot be inserted. If, however, the bottom of the bottle were bored through, and the opening covered with a rubber membrane, the cork could be slipped in without difficulty.

The function of the Eustachian tube.—The Eustachian tube, as stated on page 371, runs from the back of the nose (nasopharynx) to the middle ear. It therefore permits this part of the ear to communicate with the outside air. By this means the pressure of air on the two sides of the drum membrane is equalized. It must be remembered that the air around us has a great weight (p. 140). It presses upon every square foot of our bodies with a weight of one ton. If the pressure in the middle ear were not as great as the pressure of the atmosphere, the drum membrane would be pushed in and could not move freely in and out when sound waves struck it. It would be pushed in toward the cavity of the middle ear and be as rigid as a board and not sensitive to rapid vibrations. In sailing, for example, the sail is stiff and rigid when the wind is on our beam. When the boat is headed into the wind, however, the sail flaps to and fro, since the pressure on its two sides is practically equal. Probably all of us at one time or another have known the slight deafness which accompanies a cold in the head. This is caused by the Eustachian tube becoming blocked by the swelling of the mucous membrane around its lower opening (in the nasopharynx). The air within the middle chamber of the ear becomes partially absorbed into the blood, and the slightly greater pressure of the atmosphere then upon its outer surface prevents the drum membrane from moving freely. Blowing the nose or swallowing will often, by momentarily forcing air up the tube, restore for a

time, at any rate, the hearing to its usual acuteness. It is not a wise practice, however, to open the tube by blowing the nose when it is closed as the result of a cold. Infection may be forced into the middle ear and cause inflammation, with earache and perhaps worse consequences.

The tube is not always open, but only during swallowing. This is sufficient to keep the air pressures equal. If it were open all the time, one's own voice would send sound waves up to the middle ear and cause an unnecessarily loud noise.

In rapid airplane descents from a high altitude, equalization of pressure between the middle ear and the atmosphere may not occur promptly enough. If the Eustachian tube does not open as the descent is made, the air pressure in the middle ear remains at that of the high altitude, while the atmospheric pressure on the outer side of the tympanic membrane increases rapidly. The membrane is forced inward and may rupture. In order to avoid this accident the Eustachian tube is opened by swallowing a number of times in quick succession.

The three characteristics of sound.—The ear can distinguish between the *pitch, quality,* and *intensity* of different sounds.

Pitch depends entirely upon the *number* of vibrations or waves which strike the drum membrane per second—the greater the number the higher the pitch. We speak of a low or a high note, of the bass and treble of the piano, or of a bass or soprano voice, meaning that the sounds are of low or high pitch. The greater the number of waves per second the shorter, of course, they must be (Fig. 39.9*A*).

Quality or *timbre* is what distinguishes harsh sounds or noises from musical notes, and the tones of different instruments from one another. The tone of a violin, for example, is quite different from the tone of a bugle, a piano, or a flute. The quality of a sound is not due to the frequency of the vibrations but to the form of the sound waves. Sounds of the same vibration frequency—that is, of the same pitch—may differ greatly in quality. The form of the sound waves depends in turn upon the number and character of the simple harmonic waves of which it is composed (Fig. 39.9*C*).

Intensity or *loudness*. The loudness of a sound depends upon the amplitude of the sound waves (Fig. 39.9*B*). The firing of a cannon causes a great commotion in the atmosphere; huge waves

travel out from the point of the explosion to strike the drum membrane. We hear a loud report. A pin dropping upon the floor gently ruffles the air with tiny ripples. The very large waves will, of course, strike the air with greater force, cause the drum membrane to be forced in and out violently, and indeed may rupture it. The stapes is pushed in and out of the oval window more energetically.

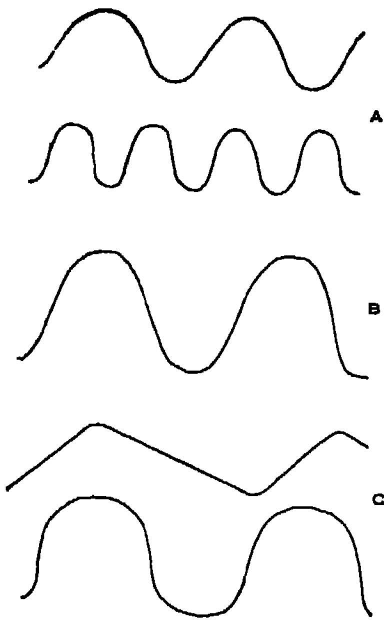


FIG. 39.9. Sound waves: *A*, waves of different frequency, illustrating pitch. *B*, a wave of greater height than those shown in *A* or *C*, illustrating intensity or loudness of sound. *C*, waves of different forms to illustrate quality or timbre.

The stimulation of the hair cells is consequently more intense with a loud than with a soft sound.

How the ear distinguishes difference in pitch.—Even animals can tell a high-pitched from a low-pitched tone. The human ear is very sensitive to differences in pitch. A person with a "good ear" can very accurately distinguish between two tones differing from each other by only one or two double vibrations per second; that is, if 100 vibrations strike the ear per second, the tone is perceived as being lower in pitch than one in which the vibrations are 101 per second.

Two theories have been proposed to explain the pitch-discriminating faculty of the auditory mechanism. According to one theory the basilar membrane is set into vibration as a whole by the sound

waves transmitted to it from the tympanic membrane through the ossicles of the middle ear and the fluid of the internal ear. Sound waves of, say, 10,000 double vibrations per second thus induce vibrations of the same frequency in the basilar membrane and cause a corresponding number of taps or pulls upon the processes of the hair cells. Ten thousand impulses per second would therefore be discharged along each fiber of the acoustic nerve. Impulses of this frequency would be interpreted by the brain in such a way as to give a sound sensation of a given pitch. A sound of, say, 5,000 double vibrations per second would be interpreted as one of lower pitch. This is known as the *telephone theory* because, like the operation of the telephone, sound waves striking the drum membrane and conveyed to the basilar membrane (corresponding to the telephone transmitter) set up nerve impulses (electrical impulses in the telephone wire) of exactly the same frequency and transmit them to the brain (which corresponds to the telephone receiver).

This theory, though it has the advantage of simplicity, can no longer be entertained, for it has been shown without question that a fiber of the acoustic nerve cannot transmit impulses at the high frequency that would be required for the appreciation of high-pitched sounds. The upper limit of frequency of impulses which a nerve fiber can transmit is about 1,000 per second (see p. 272).

The theory which explains the known facts most satisfactorily is founded upon the principle of *sympathetic resonance*. It is known as the *harp, resonance,* or *place theory*. This theory, which was elaborated by Helmholtz, the great German physicist and physiologist, has been amply supported by modern experimental work. The point which it emphasizes is that the basilar membrane does *not vibrate as a whole* but only at one part in response to a given sound frequency. That part of the membrane alone vibrates which is "in sympathy" or in tune with the sound.

The essential part of this theory will be made clearer by an example. If close to a stringed instrument, such as a harp or a piano, a note is sounded upon a bugle, bell, or any other sounding body, that particular string of the harp or piano is set into vibration which, if it were plucked or struck, would itself give out the same note. The instrument gives out a faint sound, apparently of its own accord, in perfect tune with the bugle's note. In other words, the sound waves from the bugle pick out only that string of the harp

or piano and set it vibrating which can produce sound waves of the same frequency. This is a simple example of sympathetic resonance.

Now the spirally twisted, ribbon-like basilar membrane contains a great number of fine cross fibers. These, like the strings of a piano or a harp, are of graded lengths and probably also of graded thicknesses and tensions. The number of fibers are, however, much greater than the number of strings in a piano or in any other stringed instrument. There are about 24,000 fibers. The longer fibers, which may be compared to the bass strings of the piano, lie near the top of the spiral; the shorter treble fibers are found at the bottom. When the basilar membrane is removed from its position,

FIG. 39.10. The basilar membrane. The cross lines indicate the fibers, of which there are some 20,000. The narrow part of the membrane is at the base, the wide end at the top of the cochlea.

uncoiled, and laid flat, it is found to be only about $1\frac{1}{2}$ inches long. It is $\frac{1}{125}$ inch wide at its narrow end but nearly double this width at its broad end. Hence, if we consider the 24,000 fibers which stretch across it as strings, then we have a tiny piano or harp-like instrument, which may vibrate and show sympathetic resonance (Fig. 39.10).

We can now see how a note of a certain pitch will set, not all the fibers of the membrane into vibration, but only those which can vibrate at the same or nearly the same rate as the vibrating body which gave rise to the note. The vibrations of these particular fibers stimulate the hair cells immediately overlying them, and no others. Impulses travel along the nerve twigs, with which the cells are supplied, to reach certain cells in the brain.

Thus, we may conceive that the nerve fibers composing the acoustic nerve and arising in the hair cells in one or other part of the basilar membrane transmit impulses to nerve cells in a corresponding and definite part of the cortex of the temporal lobe. The situation in the cortex of the cells receiving these impulses is the basis upon which the pitch of a sound is appreciated. In the last analysis, therefore, pitch perception, like any other sensation, is a matter of *where* in the brain the impulses arrive (p. 277). The basilar membrane through its resonating property serves to localize

the vibrations to hair cells at a certain place and to direct impulses to a limited region of the cerebral cortex, but the ultimate interpretation of the impulses is left to the brain.

The following observations confirm our belief that this theory truly explains the way in which the ear distinguishes between notes of different pitch. (1) Boilermakers who have for long periods been exposed to the clang of high-pitched noises sometimes become quite deaf to high tones. Lower tones are heard clearly. Examination of the inner ear of men suffering from this form of deafness has shown that the fibers of the basilar membrane at the base of the cochlea—that is, the short, treble fibers—have been destroyed. (2) Destruction of these fibers has also been caused by experiments upon animals, in which they have been forced to listen for a long time to loud, shrill noises.

To solve the mystery of the mental process whereby an impulse arriving in the brain from the upper part of the cochlea gives the sensation of a low tone, whereas one arising in the lower cochlear region is heard as a high note, seems as hopeless a task as to explain why stimulation of the retina within a limited range of wave lengths gives a sensation of light and color.

The sensitivity of the ear. The threshold of hearing.—By reducing the intensity of a sound until it is just perceptible the extreme limit of the sensitivity of the ear can be determined. This is called the *threshold of hearing.* But the sensitivity of the ear varies widely with the pitch, being greatest (i.e., the threshold is lowest) for sounds with frequencies between 500 and 5,000 double vibrations per second. A sound wave of a frequency within this range arouses an audible sensation though it causes a pressure variation no greater than one twelve billionth of the pressure of the atmosphere at sea level, and a movement of the tympanic membrane of less than one ten millionth of a millimeter. The ear is found to be progressively less sensitive as the sound frequencies are increased or reduced beyond this range. Sounds of very high or of very low pitch in order to be audible must be increased in intensity several thousand times above the intensity required for sounds around 1,000 double vibrations per second. Sounds with vibration frequencies above 30,000 per second or below 16 per second, no matter what their intensity, are inaudible to the human ear. Frequencies which cause no audible

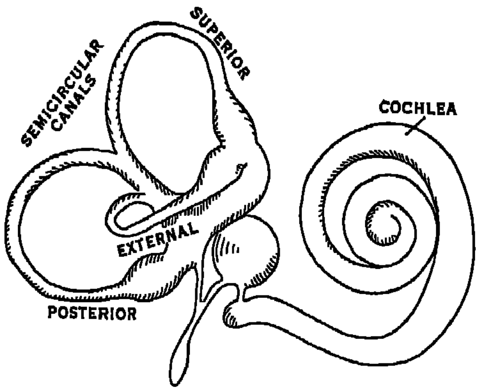


FIG. 39.11. Diagram of the semicircular canals and cochlea. (*Redrawn from Gray's Anatomy.*)

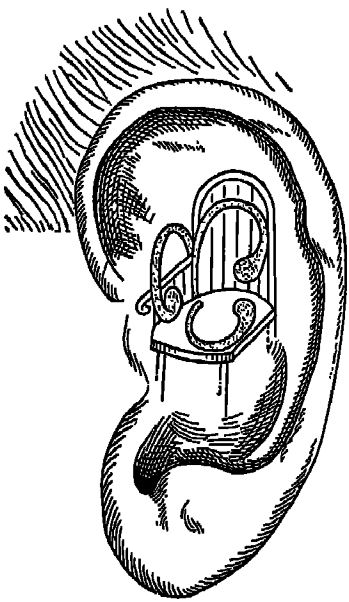


FIG. 39.12. A diagram to show the different planes of the semicircular canals in relation to the head. The left ear is represented. The canals are at right angles to one another and in this are comparable to the arm, seat, and back of a chair.

sensation may, however, be felt, the lowest frequencies giving a low rumbling sensation. Some vibrations if very intense may give rise to pain in the ear.

The intensity of a sound sensation—that is, the loudness of a sound of any given pitch—depends upon the frequency of the impulses[2] discharged along the fibers of the acoustic nerve to the brain. With respect to the relationship of impulse frequency to intensity of stimulation and sensation, the sense of hearing does not differ, therefore, from the other senses (p. 271). The greater the amplitude of the waves set up by a sounding body and transmitted to the internal ear, the more forcibly will the basilar membrane vibrate, the stronger will be the stimulus applied to the hair cells, and the higher will be the frequency of the impulses discharged.

FIG. 39.13. Successive positions taken by a cat in falling from a height.

THE SEMICIRCULAR CANALS

The inner ear holds, in addition to the cochlea with its spiral passages and the organ of Corti, another organ, which is not concerned at all with the sense of hearing, but performs an entirely different function. This organ consists of a set of three sickle-shaped tubes—*the semicircular canals* (Figs. 39.11 and 39.1). They

[2] This should not be confused with the frequency of the sound waves, which ranges up to 30,000 per second, whereas the nerve impulses have a maximum frequency of only 1,000 per second.

are filled with fluid. To these canals we owe the ability to maintain the balance of our bodies when we are sitting or standing, walking, running, or riding a bicycle. They also enable us to know the direction in which our bodies are moving—forward, backward, to one side, up or down,—even though our eyes are closed or blindfolded. One of these canals lies horizontally. Another is placed vertical to the first and having a relation to it like the back of a chair to the seat

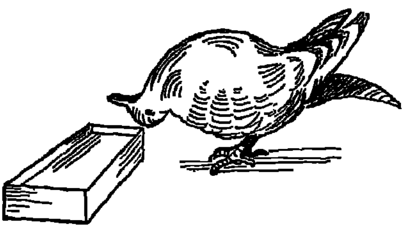


FIG. 39.14. A bird in which the semicircular canals have been injured attempting to drink. It cannot bring its head into the correct position. (*Modified from Ewald.*)

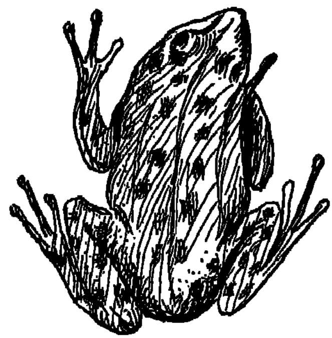


FIG. 39.15. Position of the head and body of a frog which has received an injury to the semicircular canals of the right side.

(Fig. 39.12). The third is also vertical, but bears a relation to the first two canals similar to the relation borne by the arm of a chair to its back and seat. In other words, the three canals are at right angles to one another, each lying in one of the dimensions of space. When the head and body move in any of these dimensions—up and down, from side to side, forward or backward,—the fluid within the corresponding canal, as a result of its inertia, stimulates delicate hair cells situated at one end of each canal. These receptors are supplied with fibers of the ***vestibular nerve*** which convey the impulses to the medulla oblongata and thence to various parts of the brain, including the cerebellum. The impulses are interpreted by the brain as changes in the body's position in space. Acting upon the information received from the semicircular canals the brain sends impulses to those various muscles of the neck, trunk, and

limbs which are concerned with maintaining the posture of the body.

When the semicircular canals are diseased, giddiness and difficulty in balancing the body result. When they are destroyed, the body loses its power to keep its equilibrium. The brain has lost one of its main sources of information and, in consequence, cannot send the necessary directions to the muscles which keep the head and other parts of the body in their correct positions in space. Figure 39.13 shows the successive changes in the position of a falling cat. As the animal falls through the air, its body is brought into the correct position and in consequence lands feet first (see also Figures 39.14 and 39.15). Seasickness, and the dizziness which follows swinging or running around in a small circle, are results of the excessive stimulation of the canals in one direction.

chapter 40

THE SENSES OF SMELL AND TASTE. SKIN SENSATIONS

Taste and smell are alike in that they are both chemical senses; that is, the stimulus which excites the receptors of taste and those of smell is a chemical one, and it is upon the chemical nature of a material that its characteristic smell or taste depends. Salt has a different taste from sugar because these two substances are essentially different chemically. The perfume of the rose is distinguished from the smell of the violet because, as the chemist knows, the essences from which these scents arise are not the same chemically. The sense of smell, however, is apparently different from the sense of taste, for we can smell a substance without bringing it in contact with the interior of the nose—we can smell a thing at a distance.[1] In this regard the sense of smell and the senses of sight and hearing are similar. To taste a material, on the other hand, the sense organs of taste must be stimulated more directly. We must place the material in the mouth. In this respect the sense of taste and the sense of touch are alike.

The Sense of Smell—Olfactory Sense

The sense of smell is almost incredibly acute in some animals, but is rudimentary in man. It is said, however, that certain tribes of South American Indians are aided by the sense of smell in tracking game. There are also instances on record of persons who, de-

[1] This is not an essential difference, for in order for a substance to be smelled molecules or fine particles of it must come into actual contact with the olfactory receptors.

prived of the sense of sight, have so developed the olfactory sense that they can recognize their acquaintances by smell alone!

An odorous material is continually throwing off particles of its substance—molecules—to be carried to our noses. The molecules are so few and so widely separated that they really constitute the substance itself in gaseous form. Some materials, such as ether, gasoline, and turpentine, which throw off large numbers of molecules in a short time and, as we say, evaporate quickly or give off fumes, have a very strong smell. Other materials, such as the common metals, which do not cast their particles about so freely, have little or no odor, unless heated to a high temperature. Though the proportion of its substance which it gives off may be almost infinitesimal, a material, nevertheless, may have a very powerful odor. A small piece of musk, for instance, will show no change in its size or weight after a period of several years, though it has throughout the whole time permeated a large room with its scent.

The odors of various substances.—There appears to be some relationship between the colors of flowers and their smells. Generally speaking, white flowers are more strongly scented than colored ones. Of colored flowers, red are more likely to be highly perfumed than yellow varieties, and yellow flowers are usually more odorous than blue. Though smell is a chemical sense, the smell of a material and its chemical nature do not necessarily go hand in hand, for substances which differ greatly in their chemical composition may have very similar odors. For example, some compounds of arsenic smell like garlic; nitrobenzene and prussic acid, though chemically quite different, have similar odors. Yet, with certain substances, some relationship between smell and chemical nature appears to exist, their odors increasing in strength with their molecular weights. For example, methyl alcohol is inodorous; ethyl or ordinary alcohol, which has a higher molecular weight, has a distinct odor; and the smell becomes increasingly more powerful with each alcohol higher in the scale. Again, formic acid is inodorous; acetic acid has the characteristic odor of vinegar; butyric is more powerful-smelling; and valerianic is very offensive.

How we smell.—The nasal mucous membrane is raised into three ridges or hummocks by three small bones (turbinates) which spring from the outer wall of the nose. They divide each half of the nose incompletely into four chambers or passages, placed one

above the other and running from front to back (Fig. 40.1). The inspired air flows through the lower three passages but not through the uppermost one, which lies beneath the floor of the skull. The sense organs of smell are situated in the mucous membrane (olfactory mucous membrane) of this upper passage. Substances, in order that they may stimulate the sensitive cells in this situation, must be carried there in a gaseous form mixed with the inspired air. Since the uppermost passages of the nose are, as it were, blind alleys

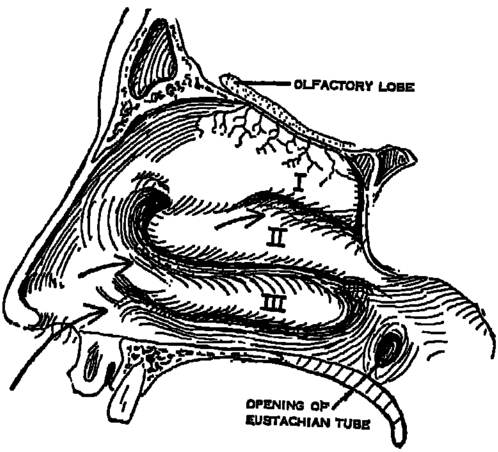


FIG. 40.1. The inner surface of the outer wall of the nose. I, upper turbinate bone; II, middle turbinate bone; III, lower turbinate bone. The olfactory area lies above the upper turbinate. The arrows indicate the course taken by the air in breathing. The area of mucosa above the upper turbinate contains the receptors of smell.

or pockets, through which the main air currents do not pass, the question arises as to how the odorous gases reach the sensitive cells. Experiments have shown that they are carried upward by eddies from the lower air currents. We have all noticed the air currents rising from a radiator, or wherever cold and warm air meet. Similar air movements occur in the nose when the cold outside air meets the warmer air within the nasal passages. These upward moving currents carry the molecules of the odorous substances to the olfactory cells. In order to smell more acutely we purposely take a short breath or sniff, which draws in colder air and increases the number and force of the ascending currents.

Some individuals are incapable of smelling certain scents. Prussic acid, employed to kill vermin, though it has a strong odor of almonds to a person with a normal sense of smell, is inodorous to a few others. For this reason deaths occasionally result from breathing this highly poisonous gas, since those who cannot smell it may

enter a room containing it in dangerous concentration and be quite unaware of its presence. The olfactory receptors after a short time become, as a rule, insensitive to any particular smell, though they remain quite sensitive to any other odor.

The olfactory cells, receptors for smell.—The olfactory cells are oblong cells with plump, rounded nuclei, embedded in the mucous

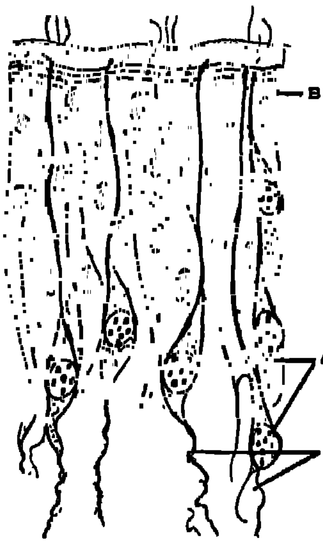


FIG. 40.2. A section of the mucosa from the olfactory area of the nose. *A,* sensitive cells (receptors for smell). *B,* supporting cells. *C,* nerve fibers.

membrane of the uppermost passage of the nose. Each cell possesses a long thread of protoplasm which passes outward to the mucous membrane. From the other end of the cell a delicate nerve fiber proceeds upward and, passing through minute holes in the floor of the skull, ends in the brain (olfactory lobe) (Figs. 40.2 and 32.15). The sensitive cells are supported by other cells which surround them. These have tufts of minute hairs (cilia), which project from the mucosa.

THE SENSE OF TASTE

In order for a substance to be tasted, it must first be dissolved. If a solid material is placed in a perfectly dry mouth, it cannot be tasted. In ordinary circumstances the saliva dissolves materials taken into the mouth as food and arouses the sense of taste.

The organs of taste.—The organs of taste are carried chiefly upon the tongue, though the mucous membranes of the soft palate, the tonsils, and the epiglottis also contain a few. If the reader examines the surface of his tongue in a mirror he will see tiny projections which give it an appearance resembling the pile of plush. These projections, called *papillae* (Plate V*c*), are absent from the undersurface of the tongue. Farther back on the upper surface of the tongue the projections become much larger, and each is surrounded by a groove and outside the groove by a ridge, giving the resemblance of a little squat tower surrounded by a moat and wall. Embedded here and there in the covering (epithelium) of both the small papillae at the tip and the larger ones toward the back of the tongue, are small collections of slender cells packed side by side in bundles. These are the sensitive cells of taste, and the oval bundles which they compose are called the *taste buds* (Fig. 40.3). Each cell is supplied with fine branches of the nerves of taste (lingual and glossopharyngeal). The taste bud opens upon the surface of the papillae by a tiny pore, and all its cells, coming together here, end in a number of fine hairlike projections. Substances in solution enter these pores of the taste buds and stimulate the hairlike ends of the cells within.

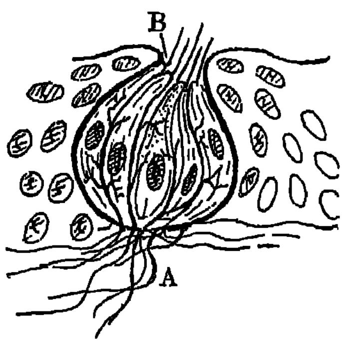


FIG. 40.3. A taste bud from the surface of the tongue. *A*, nerve fibers from taste receptors. *B*, taste pore.

The fundamental sensations of taste.—There are only five fundamental taste sensations—sweet, bitter, sour, alkaline, and salty. The various other tastes which we experience are due to a blending of these five in different proportions, and also to their combination with other sensations in the mouth besides those of taste proper. For instance, pepper and ginger are recognized more by the burning sensation which they arouse than by their actual tastes. They excite other nerves in the mouth besides those of taste. Oils are unpleasant to a large extent because of their feel. Acids are astrin-

gent, and soda water "nips." Some of the finer flavors are in reality sensations of smell. The back of the nose communicates with the mouth, and, as we eat or drink, aromas ascend to stimulate the olfactory cells. For that reason when the nose is held or the mucous membrane of the nose is inflamed, as by an ordinary cold, the sense of taste is blunted. In certain fish the outer surface of the body is furnished with taste organs. In the catfish, for instance, long processes containing taste buds are found upon the head and back and near the tail.

The fundamental taste sensations are not aroused equally well over all regions of the tongue's surface. Sweet substances, for instance, are tasted best by the tip and front part of the tongue. The small boy licking a stick of candy demonstrates this fact. Salty tastes are also best perceived by the tip, whereas the sides of the tongue are more sensitive to sour tastes. Bitterness is tasted most strongly at the back of the tongue and in the throat. A bitter-sweet substance tastes sweet when first taken into the mouth, the bitter element being most noticeable after the substance has passed over the back of the tongue and has been swallowed. The central area of the tongue is scarcely at all sensitive to taste.

Skin Sensations

Five sensations—*touch, pain, heat, cold,* and *pressure*—may be aroused by stimulating the skin. If, for example, a light object, such as a pencil or a wisp of absorbent cotton, is drawn across the skin, a sensation of light touch is aroused. If the pencil is pressed more firmly upon the skin, it gives the impression of weight or pressure. If the pencil is pressed still more firmly, or if a pin is used to prick the skin, pain is experienced. The sensations of heat and cold are so familiar to everyone that a description of them is unnecessary.

The receptors of the skin.—Some skin sensations are aroused by mechanical stimuli of different degrees of intensity which excite distinct types of receptor. Those which respond to light touch are situated just beneath the surface of the skin and near the hair sockets; they are called the *corpuscles of Meissner.* Those excited by pressure are situated more deeply and are known as *Pacinian corpuscles.* The sensations of heat and of cold are also dependent

upon special receptors; the former are called the *end organs of Ruffini* and the latter the *end bulbs of Krause* (Fig. 40.4).

With the exception of those for pain, each type of skin receptor is especially designed and adapted to respond most effectively to one type of stimulus—that is, to set up impulses in the nerve fiber with which it is supplied. The pain receptors are for the most part

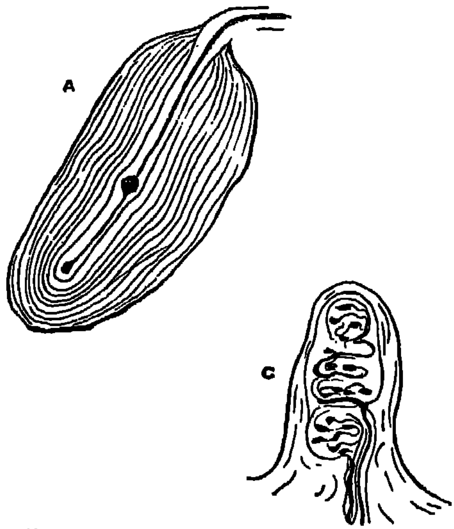


FIG. 40.4. Receptors of the skin: *A*, for pressure (Pacini's corpuscle); *B*, for temperature (end bulb of Krause); *C*, for touch (Meissner's corpuscle). The heavy lines in the drawings represent nerve fibers entering the centers of the receptors.

simply bare nerve endings, there being as a rule no specially constructed end organs. Pain in the skin is aroused by almost any form of stimulus provided that it is sufficiently intense. This sensation serves as a warning against threatened injury. It is obviously essential for the comfort of the individual that pain should not be aroused by stimuli of mild degree. The pain endings require, therefore, a relatively strong stimulus for their excitation. It is equally important that any type of stimulus, whether mechanical or thermal, when it reaches such an intensity as might cause tissue damage, should excite the pain endings and thereby signal the central nervous system of the danger. In certain diseases of the nervous

system the nerve fibers which normally carry impulses of pain are destroyed or fail to function. Severe damage to the parts so deprived of their unpleasant but beneficent protector is then a common occurrence.

The various types of receptors are scattered broadcast over the surface of the skin. If the different kinds of stimuli to which they respond—heat or cold, touch, pressure, and pinprick—are applied

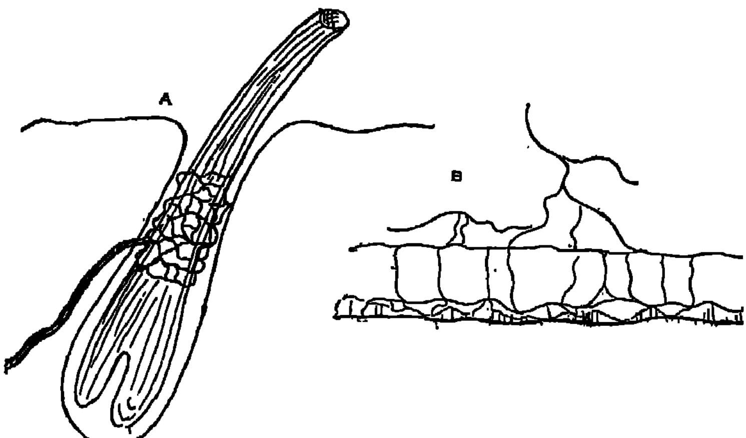


FIG. 40.5. Ending of pain fibers. *A*, within a hair socket; *B*, in the cornea.

to the skin in turn, the location of the several receptors may be detected. The small areas which, when touched, pricked, or heated, give rise to one or other of these sensations are spoken of as "spots." So, we find hot and cold spots, touch spots, etc. The touch spots lie on the "windward" side of the fine hairs covering the skin. For this reason merely touching the tips of the hairs causes a sensation of touch. When touched, the hair, acting as a tiny lever, moves the skin at its root and so stimulates the touch spot. Pain fibers also form a meshwork within the hair sockets (Fig. 40.5A). The cornea of the eye possesses only pain fibers, and these are very sensitive (Fig. 40.5B). Consequently stimuli which will produce only a sensation of light touch if applied to the skin will, when applied to the cornea, cause pain. This is a means of protection for the eye; there is no need for touch or temperature sensations in this situation,

but even light contact or moderate change in temperature may be injurious to the eye. Thus the painful sensation serves as a warning, even if the cornea is touched ever so lightly. The mucous membranes of the nose and mouth are, like the skin, sensitive to heat and cold, pressure, pain, and touch. The sensation of touch is particularly acute upon the tip of the tongue.

part IX

Endocrine or Ductless Glands

Chapter

of internal secretion.[1] Their secretions are known as *hormones.*[2] From the many chemical substances in the blood, the cells of these glands manufacture secretions with very powerful effects. They take in their raw materials by the front door—the arteries—and turn the finished product out at the back door—the veins or lymph vessels. Thence the hormone is carried to all parts of the body (Plate VIII*a*).

These glands are little chemical laboratories of marvelous ingenuity and can bring about apparently miraculous effects by their

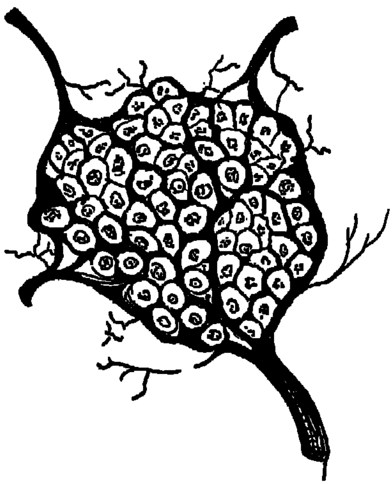


FIG. 41.2. Plan of a ductless gland —a gland of internal secretion. Note the rich blood supply, the capillaries (heavy black lines) running between small groups of cells. In some glands the cells are arranged in cords, as in the anterior pituitary gland; in others the cells are in small groups or clumps and in others, as in the thyroid, they are arranged in well-defined alveoli (Fig. 41.8).

secretions. It is the action of one of these secretions that paints the plumage of the male bird in such brilliant colors and also prompts its song. Others cause the growth of bone and direct the development of stature along normal lines—overactivity of this gland or underactivity of that, and a giant or a dwarf is made. Others influence various mental processes—instincts, emotions, and intelligence. In order that mind and body may be healthy and normal, all the various ductless glands must pour their secretions into the blood stream in exactly the right amounts. None must produce too much

[1] In this section only four endocrine glands are described—the pituitary, thyroid, adrenals, and parathyroids. The internal secretion of the pancreas (insulin) has been discussed in Chapter 26 and the gonads in Chapter 44.

[2] Hormone is a general name given to any chemical substance which, having been formed in the body and carried in the blood stream to another organ or tissue, excites it to activity (see also pp. 180, 200, and 204).

nor too little of its very potent chemical. If it does, abnormalities in growth and development or in behavior result (Fig. 41.3).

Some of the endocrines are of such a size and prominence that they did not escape the notice of the ancient philosophers. Their functions were pondered and speculated upon, and many fanciful ideas were suggested to account for their existence. The discovery

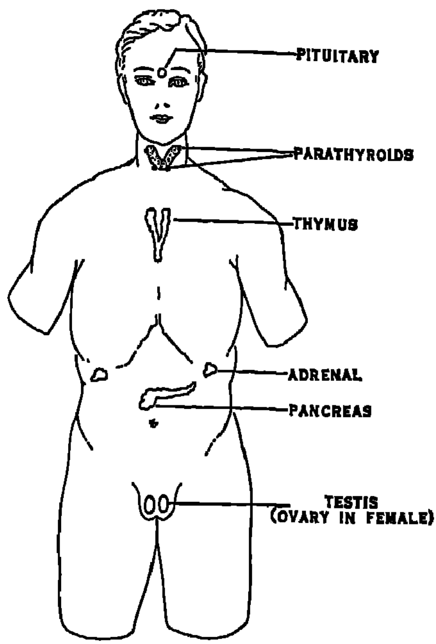


FIG. 41.3. Positions of the various endocrine organs. The thyroid, with which the parathyroids are closely associated, is shown but not labeled. The ovaries (not shown) are situated in the pelvis close to the uterus. The endocrine function of the thymus, if any, is unknown.

of their true functions is comparatively recent. Previously, the central nervous system was believed to play the dominant role in the control of bodily functions; its authority was thought to be supreme and undisputed. With the discovery of the endocrine glands an entirely new and quite unthought-of type of control was brought to light. Their influence, though not so evident as that of the nervous system, is quite as important in their own sphere.

The internal secretions, with the exception of those formed by the adrenal medulla and the posterior lobe of the pituitary, govern slowly moving processes, such as the growth of the skeleton, the

development of the sex organs, and the metabolism of food materials—processes measured by hours, months, or years; whereas the nervous system presides over those rapid processes of thought, mucular movement, and the external secretions of glands—processes measured by fractions of seconds, or at the most minutes.

The Thyroid Gland

First will be considered a gland with which everyone, to some extent, is familiar. This is the thyroid, which lies beneath the

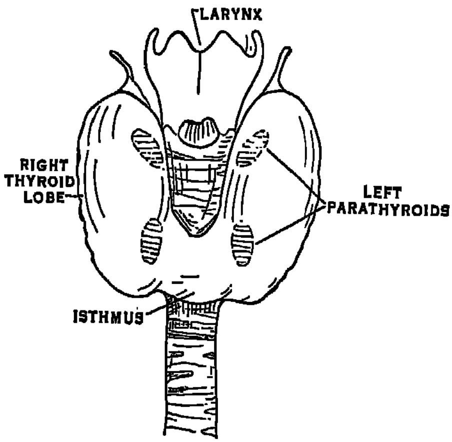


Fig. 41.4. Relationship of the thyroid to the larynx and trachea. The parathyroids lie behind the thyroid or are embedded in it.

muscles of the neck and embraces the sides of the larynx and upper part of the trachea (Fig. 41.4). When greatly enlarged, it constitutes the condition known as *goiter.*

In Switzerland, in the valleys of the Alps, there was commonly to be seen, until recent times, a type of dwarf known as a *cretin* (Figs. 41.5 and 41.6*A*). A cretin is the direct result of the absence or the extreme deficiency of the thyroid hormone in infancy or childhood. These individuals are truly the most pitiable and grotesque parodies on mankind.

Cretins have a characteristic appearance which usually cannot be mistaken. Their growth is retarded or arrested at an early age. Their bodies are squat and flabby. They are mentally defective and often imbecile; many are deaf-mutes. Their low

intelligence is usually quite evident from their facial expression. Their features are coarse and ugly, often goblin or gargoyle-like. The forehead is low, the bridge of the nose depressed (saddle-shaped), the lips large and loose, and the tongue, which appears larger than normal, protrudes from the partly open mouth. The skin of the face and of the body generally is thick, pale, and pasty. The hair is dry, coarse, and sparse. Cretins are sexually undeveloped. Their basal metabolism is much below the normal value. The word *cretin* is a corruption of the French word *chrétien,* meaning Christian, and was originally used in speaking of these unfortunates much in the same sense as the English words *innocent* and *simple* are applied to the feeble-minded.

FIG. 41.5. A cretin. (*After Joll.*)

Cretinism and goiter—hypothyroidism.—Though cretins were more common in Switzerland than in other parts of Europe, they were by no means confined to that country. Cretinism was at one time not uncommon in England, especially in Derbyshire. They are seen occasionally on this continent. But it was in the valleys of the Alps, of the Pyrenees, in the Tyrol, and in the Himalayas that it was seen most frequently.

It was not until the thyroid gland was removed from young animals that the cause of cretinism was revealed. Sir Victor Horsley, a London surgeon, performed this operation upon young monkeys, and showed that the symptoms which followed the operation were practically identical with those of human cretinism. Removal of the gland from other young animals causes arrested growth (Fig. 41.7). Through this work the responsibility for cretinism was definitely fastened upon the thyroid.

Several questions had still to be answered: Why is cretinism common in certain regions and practically unknown in others? Why does the gland fail to perform its normal function? The usual answer given to these questions was that the drinking water was at fault. Even during the first two decades of the twentieth century authorities accepted this explanation. The specific thing

which was supposed to depress thyroid function was unknown, though some thought it was an excess of calcium (lime), others that it was a microorganism.

Without going further into detail, it may be said that the question has at last been settled. It is not due to something in the water that should not be there, such as lime or germs, but to the absence of iodine from water and food. For this knowledge we

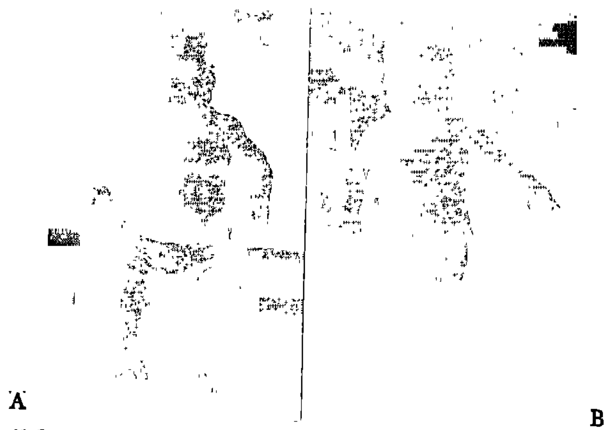


Fig. 41.6. An infant cretin, *A; B,* after treatment with thyroid extract. (*After Braithwate.*)

are indebted to an American scientist, Dr. David Marine, who showed some 30 years ago that thyroid disease (goiter) in brook trout could be cured by the addition of very small amounts of iodine to the water in which they lived. He also showed that thyroid enlargement in children could be prevented by small doses of iodine.

This explains why cretins are practically never seen on the seacoast. The sea is an inexhaustible storehouse for iodine, which finds its way into the food and the drinking water of the inhabitants along the coast. It is practically always in inland territories that thyroid deficiency is seen—particularly in the mountains and on the high land, since they, as a rule, are farther removed from the iodine supplies of the sea. Examination of the soils of goitrous districts has shown that they are poor in iodine.

The thyroid must have iodine in order to manufacture its secretion. Without this element it is unable to produce its hormone in sufficient amounts. The gland becomes enlarged, but the enlargement is made up to a large extent of worthless tissue, its alveoli filled with a secretion of very low potency. The essential glandular tissue has degenerated and, though the gland is of greater size, it is a fraud, being made up largely of fibrous tissue and large irregular spaces instead of the small and regularly shaped alveoli (Fig.

FIG. 41.7. The effect of the removal of the thyroid upon the growth of rabbits. The three rabbits are the same age. The thyroids of the two animals on the right had been removed some time before the picture was taken. The animal on the left is normal. (*After Basinger from Schafer's Endocrine Organs.*)

41.8). The tissue of such a gland has a very low concentration of iodine.

Cretinism is seen much less commonly today, and when it does occur it is rarely the result of goiter; it is usually seen in babies and is then due to defective development of the thyroid gland before and after birth. There are two reasons why the cretin is now a rarity. In the first place, the tendency to goiter in those parts of the world where it used to be prevalent has been greatly reduced by supplying iodine to the population, especially to growing children. On this continent as well as elsewhere it has become the custom to add minute amounts of iodine to table salt. The second reason why cretinism is now seen infrequently is that thyroid deficiency can be easily and quickly corrected by treatment with the thyroid hormone obtained from the glands of sheep. In 1894 Dr. George Murray, an English physician first treated persons suffer[illegible] from thyroid deficiency with injections of a glycerine extra[illegible]

sheep's thyroid tissue. Of all the discoveries in the field of medicine this proved one of the most brilliant. Soon it was shown to be unnecessary to give the treatment by injection. Today sheeps' glands are dried and powdered, compressed into tablets, and taken by mouth. If thyroid deficiency is recognized at an early age all the defects which have been described as characteristic of cretinism can be corrected. Growth and development—bodily, mental, and sexual—proceed in normal fashion, and if the treatment is maintained,

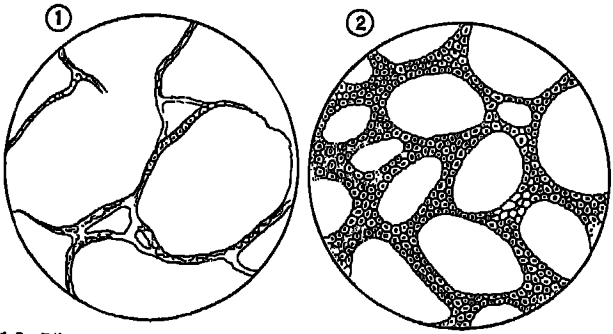


FIG. 41.8. The microscopic appearance of a goitrous thyroid (1) compared with that of a normal thyroid (2). (See also Plate VIII*a*.)

as it should be to the end of life, no signs of thyroid deficiency recur (Fig. 41.6*B*).

Should the thyroid, as a result of disease, fail in its function after adult life has been reached—i.e., after growth has ceased, and mental and sexual development has attained maturity—a state develops which in its essentials is strictly comparable to cretinism. The effects upon growth and development, which are so prominent in the cretin, are, of course, absent. But the mental processes and sexual functions are depressed. The basal metabolism is below normal, the skin dry, thick, and puffy, and the hair sparse, dry and brittle. This condition is called *myxedema.* It is promptly relieved by thyroid hormone in the form of tablets of dried thyroid tissue or by *thyroxine,* the synthetic thyroid hormone (p. 410).

The effects of an excess of thyroid hormone (hyperthyroidism).—Like most of the other endocrine glands the thyroid may secrete an excess of its powerful hormone. In some instances the excessive secretion is due to a tumor of the gland composed of actively func-

tioning thyroid tissue. In other instances there is no definite tumor but the entire gland is stimulated to increase its hormone production. The gland becomes considerably enlarged. What stimulates the thyroid in this way is unknown, but it is likely that the stimulant action is brought about through a hormone produced by the pituitary gland (p. 413).

When a normal animal is treated continuously with fairly large doses of the thyroid hormone, characteristic effects make their appearance within a few days. The same effects would follow if a normal person were given corresponding doses. The heart rate increases, the metabolism is raised, and there may be trembling of the limbs and extreme nervousness. These effects of overdosage with the thyroid hormone are precisely the symptoms from which a patient suffers when his thyroid gland becomes overactive. In addition, the eyes, in many instances, bulge prominently and give the patient a staring expression. The disease, for this reason is called *exophthalmic goiter* (Fig. 41.9).

FIG. 41.9. Illustrating the prominence of the eyes in exophthalmic goiter. (*After Crotti.*)

Thyroid experiments upon lower animals.—The thyroid hormone has a remarkable effect upon the development (metamorphosis) of frog larvae—ordinarily known as tadpoles. When a number of these creatures which have just recently been hatched are divided into two groups and one group feeds upon thyroid tissue, or thyroid extract is added to the water in which they live, they develop into frogs much more rapidly than the other group. The members of the latter group, which are not given treatment of any kind, develop in the usual way and in the usual time and therefore serve as *controls*—i.e., as normal standards for comparison (Fig. 41.10).

If the thyroid glands are removed from the members of one group of tadpoles, and they are thus deprived of thyroid hormone, they do not metamorphose, whereas the members of a control group develop into frogs in the usual time. If, however, thyroid

tissue is fed to the thyroidless larvae, metamorphosis proceeds in a normal fashion and at the usual rate (Fig. 41.11).

Thyroid function has been tested out on another close relative of the frog family. In Mexican waters there lives a strange creature known as the axolotl. The axolotl is a sort of halfway house along the evolutionary path between a fish and a frog. It looks like a huge tadpole—for it is several inches long—that had started out

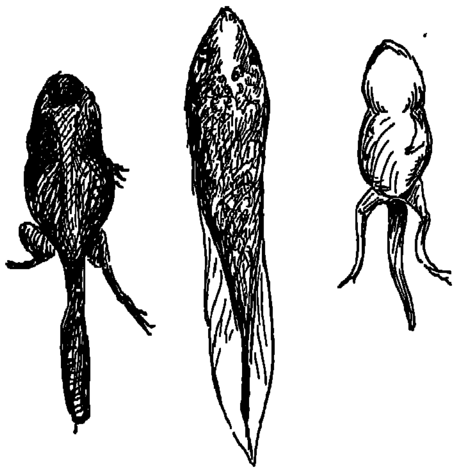


FIG. 41.10. The effect of thyroid extract upon the development of tadpoles. The three animals are of the same age. Those on the right and the left have received thyroid extract. The one in the center has not been treated. (*After Swingle.*)

to be a frog but remained a grotesque-looking object with gills, a finned tail, a square head, and short fore and hind limbs. This is the usual adult form of these creatures; they breed in this form, most of them never developing into land animals and a few others doing so very, very slowly. If an axolotl is fed upon beef thyroid, even one or two meals, it develops into a land animal. It loses its gills and tail and develops air-breathing organs. The head becomes oval and the eyes prominent. It comes out of the water and lives on land (Fig. 41.12).

Here is an instance in which an animal—forsaken, as it were, at a certain wayside station in the evolutionary journey—has been brought a step further by an internal secretion. These facts make one wonder just how important a part the ductless glands have played in the evolutionary process.

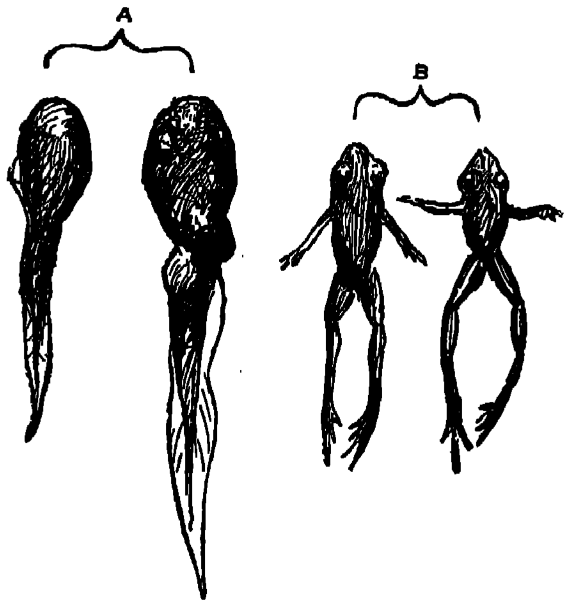


FIG. 41.11. The effect of the removal of the thyroids upon the development of tadpoles. *A*, thyroidless tadpoles. *B*, normal frogs of the same age as *A*. (*After Allen, redrawn.*)

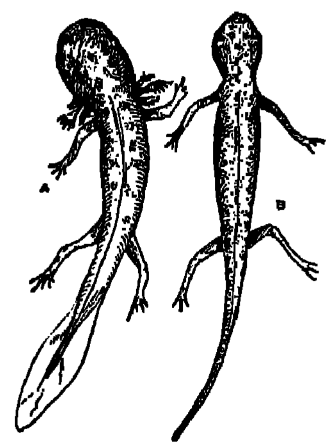


FIG. 41.12. Axolotls. *A* has not been treated. *B* has received thyroid extract. Note the disappearance of the gills and the fin from the tail.

Summary of thyroid function.—From the results of the many experiments upon animals and the innumerable observations on man, we are left with no doubt concerning the important functions of the thyroid gland. It absorbs iodine and other materials from the blood, producing from them a hormone which controls the growth and development of the body and stimulates oxidations in all the tissue cells. In excess, the hormone raises the metabolism above the normal level; if secreted in less than normal amounts it depresses heat production.

A substance has been synthesized which, if not identical chemically with the hormone as produced by the thyroid gland, at least exerts almost identical effects. It is called *thyroxine*.

chapter 42

THE PITUITARY GLAND

The pituitary gland, or *hypophysis cerebri*, is the most important endocrine gland in the body, for upon its activity the functions of

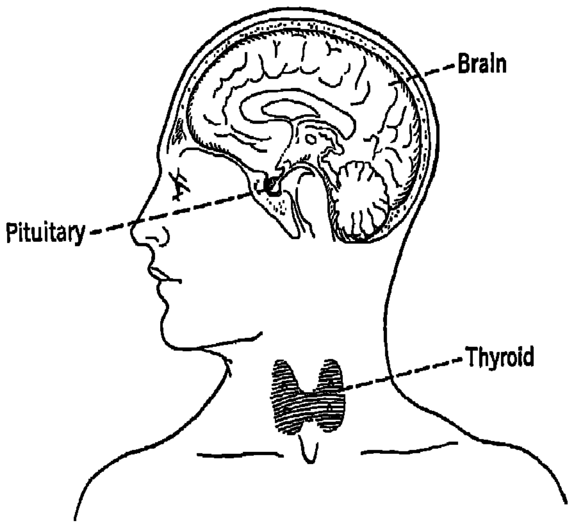


FIG. 42.1. Section of the brain between the hemispheres to show the position of the pituitary.

most of the other endocrine glands depends. Yet in man this gland is scarcely larger than a cherry. It lies at the base of the brain, to which it is attached by a short stem or stalk (Figs. 42.1 and 42.2).

The pituitary gland is made up of two main parts, or *lobes* as they are usually called—*anterior* and *posterior*—which, though of quite different embryonic origins, have become fused together. The anterior lobe has developed from a hollow outgrowth pushed upward from the primitive mouth of the embryo, and the posterior

lobe as a downgrowth from the base of the brain. A narrow band of tissue along the line of fusion of these two parts and of the same origin as the anterior lobe, is known as the *intermediate lobe.*

These three parts of the pituitary have entirely different endocrine functions and will therefore be described separately.

The anterior lobe.—The immense physiological importance of this part of the pituitary has been discovered only within recent years. Upon the hormones which it secretes the activities of most of the other endocrine glands—thyroid, adrenals, and ovaries or

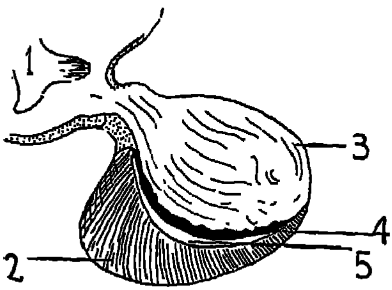


FIG. 42.2. Diagram of pituitary. 1, third ventricle of the brain; 2, anterior lobe; 3, posterior lobe; 4, intermediate lobe (black); 5, cleft at line of fusion of embryonic parts.

testes—depend. The growth of the skeleton is also under its control. It is with reason, therefore, that the anterior lobe of the pituitary has been called the master gland of the endocrine system.

The indispensability of the anterior lobe of the pituitary for many physiological processes can be shown in a striking manner by removing it from an animal and studying the effects which follow. If this operation, which is called *hypophysectomy,* is performed upon a young animal, growth ceases (Fig. 42.3). The thyroid gland and the cortex of the adrenal glands shrink (*atrophy*) and fail to produce their hormones in sufficient amounts. The animal does not develop sexually, because its sex glands—ovaries or testes—are not urged to produce their hormones; these glands also shrink and become inactive. In adult animals the effects upon the thyroid, adrenal cortex, and sex glands and the suppression of their secretions are also clearly evident. Removal of the anterior lobe at whatever age causes a profound fall in the blood sugar (glucose), and death may occur in generalized convulsions. These defects can be largely corrected by injections of the hormones extracted from the anterior lobe. Six hormones or principles have been extracted from the an-

terior lobe in nearly pure form. Each hormone so prepared produces one effect predominantly and has little or no effect which could be attributed to any of the other five hormones.

The hormone which stimulates the growth of the tissues generally —bones and soft parts—is called the *growth hormone;* the one which stimulates the thyroid and maintains this gland in a healthy and active state is called the *thyrotrophic hormone;* the hormone which

FIG. 42.3. The effect of hypophysectomy upon the growth of a young animal. Two puppies of the same litter. The animal on the right was hypophysectomized a few weeks previously. (*Dandy.*)

exerts a corresponding effect upon the adrenal cortex is termed *adrenotrophic,* and those (two in number) which stimulate the gonads (testes or ovaries) are called *gonadotrophic.* The sixth hormone stimulates the production of milk and is called *prolactin.* The actions of the gonadotrophic hormones and of prolactin are described in Chapter 45.

The anterior lobe of the pituitary gland has a profound effect upon carbohydrate metabolism. As mentioned above, the blood sugar of an animal deprived of its pituitary falls to a low level just as though it had been given a dose of insulin (p. 237). On the other hand, injection of an extract prepared from anterior lobe tissue causes hyperglycemia and the other signs and symptoms of diabetes (p. 237). The internal secretion of the pancreas—i.e., insulin—an a hormone produced by the anterior lobe of the pituitary are t fore antagonistic in their actions. In health the two hormo

perfectly balanced and the blood sugar is thus maintained at the normal level.

The actions of the other hormones prepared from the pituitary can also be demonstrated upon normal animals or upon those which have been deprived of their pituitary glands. Many of the defects already mentioned as following hypophysectomy can be corrected or the effects of any particular hormone exaggerated by injecting

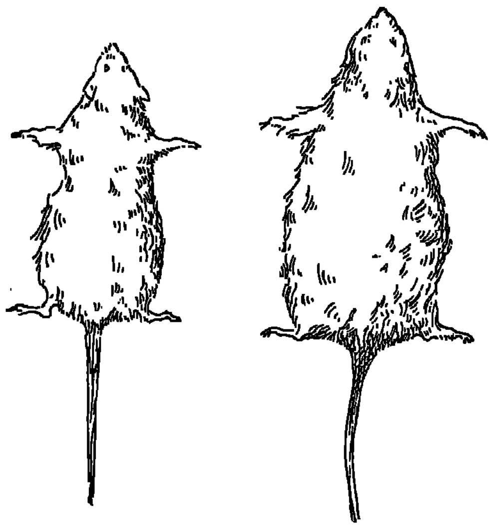


FIG. 42.4. The effect of an extract of the anterior lobe upon the growth of rats. The animal on the left has received daily injections for a period of several weeks. (*Redrawn from Evans.*)

it into a normal animal, just as hyperthyroidism can be produced by means of the thyroid hormone. Thus, by the injection of the thyrotrophic hormone the thyroid gland rendered inactive after hypophysectomy can be restored to normal appearance and function; or by means of this pituitary hormone the normal thyroid can be stimulated to produce an excessive amount of its secretion. The effects of the growth, gonadotrophic, and adrenotrophic hormones and of prolactin can be shown in a similar way. Young rats or puppies given daily doses of the growth hormone become of giant size as compared with untreated animals (Fig. 42.4).

The posterior lobe.—The first recorded experiment upon the posterior lobe of the pituitary was performed in Edinburgh over fifty years ago. A rather crude extract of the pituitary was found to constrict the small blood vessels throughout the body, and thus

to cause a sharp rise in blood pressure. This extract was later prepared commercially and sold under the name of pituitrin. Apart from its effect upon the circulation, which is called its *pressor action*, this extract has been found to have four other actions. It stimulates the contraction of smooth muscle, e.g., the uterus and intestine. Its effect upon the uterus is called its *oxytocic action*. Pituitrin increases the absorption of water from the renal tubules and thus reduces the volume of the urine; this is called its *antidiuretic action*. It also raises the blood sugar, thus antagonizing the action of insulin.

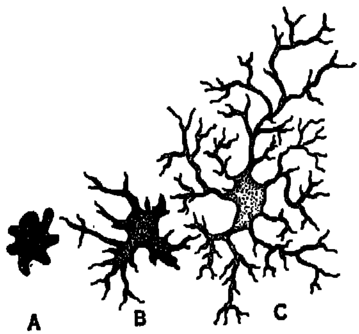


Fig. 42.5. Pigment cells (melanophores) of frog's skin, highly magnified. *A* and *B*, pigment granules confined to body of the cell or to the roots of the processes when animal is in a bright light; *C*, in darkness, the granules have migrated in to the many branching processes.

To what extent these different effects of pituitrin are due to separate hormones is not fully known, but it seems that the pressor and oxytocic actions at least are caused by distinct principles.

Another of the main actions of pituitrin is not exerted upon higher animals; but in many cold-blooded animals a principle found in the posterior lobe, though as mentioned below it is actually produced by the intermediate lobe, causes changes in skin color. The skins of many lower forms—e.g., fish, frogs, toads, snakes, and lizards—contain large numbers of irregularly shaped pigmented cells called *chromatophores*. The irregular shape of these cells is due to their possessing many branching processes. The pigment is in the form of fine mobile granules and varies in color with the species (Fig. 42.5). In frogs it is dark brown, green, or black and the cells are called *melanophores* (Gk. *melanos* = black). In the corresponding cells of some fish the pigment is red or yellow; they are therefore called *erythrophores* or *xanthophores*. By means of the color changes brought about by these cells the animals mentioned enabled to make their bodies less conspicuous in their natural

roundings and can thus more easily elude their enemies. When the animal is in shade or upon a dark background, the mobile pigment granules stream outwards into the branching processes which, since they form a rich network, darken the skin so that it blends more readily with surrounding objects (Fig. 42.6). In bright light or when the animal is against a light background, the granules

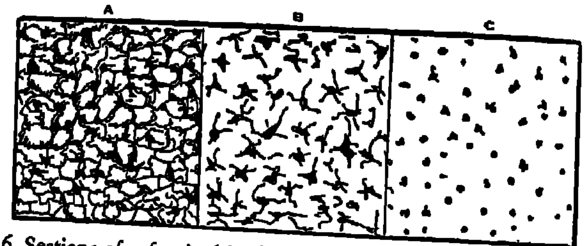


FIG. 42.6. Sections of a frog's skin (lower magnification than in Figure 42.5), showing patterns formed by pigment cells in different degrees of illumination: *A*, when the animal is in a dim light; *B*, in a medium light; *C*, in a bright light. (*After Hogben.*)

gather near the center of the cell. The cell's processes are then poorly marked and the skin becomes correspondingly pale.

An injection of pituitrin into a frog causes a migration outwards of the pigment granules. The animal's skin becomes dark, as it

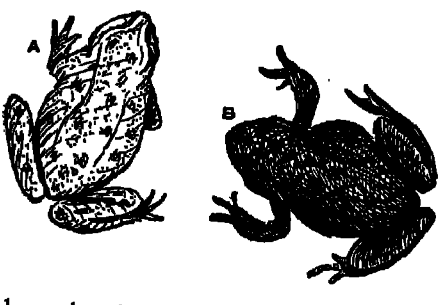


FIG. 42.7. *A*, the color of a normal frog. *B*, the same frog after the injection of an extract of the posterior lobe of the pituitary. (*Hogben, redrawn.*)

does when in shade (Fig. 42.7). This action is brought about in the living animal by a hormone formed in the intermediate lobe which is in all probability distinct from the other pituitary hormones. It is called the *chromatophore-expanding hormone*. But there must be some means of controlling the secretion of this principle in order that the skin shall change color in conformity with the animal's

environment. The controlling mechanism is connected with the eyes. When the animal is in darkness, the hormone is secreted in small amounts into the blood stream; the pigment is then dispersed and fills the branching processes. But when the retina is stimulated

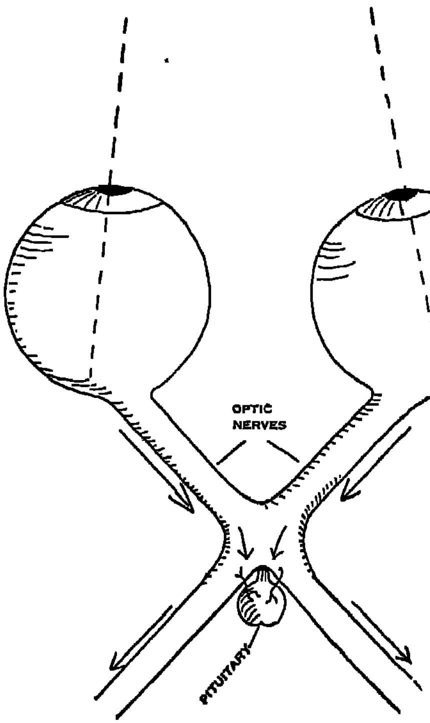


FIG. 42.8. To illustrate the manner in which light striking the retina controls the discharge of the posterior-lobe hormone of the pituitary.

by light, nerve impulses are set up and conducted by fine nerve twigs to the pituitary (Fig. 42.8). These impulses suppress the output of the chromatophore-expanding principle and as it gradually disappears from the circulation the pigment granules gather near the center of the chromatophores. This nervous-hormonal mechanism can be proved experimentally step by step. That the control of this hormone of the pituitary is dependent upon nerve impulses from the retina is shown by temporarily blinding the animal, as by sealing its eyes with wax. No change in the color

of its skin then occurs whether it is in darkness or in bright sunshine. Animals which have been hypophysectomized also lose the ability to alter the depth of the color of their skins, which are then uniformly pale (Fig. 42.9).

The well-known effect of light upon the sexual cycle of birds and of some mammals is also dependent upon the pituitary but the hormone through which this action is brought about is unknown.

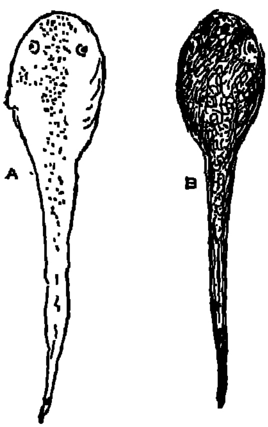


Fig. 42.9. The effects of the removal of the pituitary upon the color of tadpoles. *A*, the pituitary removed. *B*, a normal animal.

Disease of the Pituitary in Man

Acromegaly.—One of the main avenues of approach to an understanding of the glands of internal secretion has been through a study of their disorders in the human subject. The first step toward our present-day conceptions of pituitary function was made by the French physician, Pierre Marie. It was he who first described a condition characterized by overgrowth of the bones of the face, hands, and feet. The enlargement of the facial bones was seen particularly in the ridges above the eyes, in the nose, and in the lower jaw. This member in some cases reported by Marie measured 18 inches from ear to ear, and the chin was some 4 inches deep (Figs. 42.10 and 42.11). The soft tissues are also thickened, the combination of fleshy and bony overgrowth producing extreme coarsening of the features. This in many cases amounts to grotesque ugliness. The bones of the hands and feet, especially the former, show a similar overgrowth. This is no moderate enlargement, for the hand of one of these individuals may be double the size of that of a normal person of the same height.

Marie ascribed this condition to disordered function of the pituitary and called it *acromegaly* (Gk. *acro* = extremities; *megas* = big). It is due to the secretion of excessive amounts of the growth hormone.

Acromegaly develops gradually, but the changes in the facial fea-

tures are very evident when a photograph of the subject taken some five or ten years previously is compared with his present appearance (Fig. 42.12). The disease, if it progresses, is invariably fatal.

Gigantism.—Acromegaly is a disease of the anterior lobe of the pituitary commencing in adult life—that is, after the normal period of growth. But the anterior lobe may produce an excessive amount of the growth hormone during the growing period. When it does,

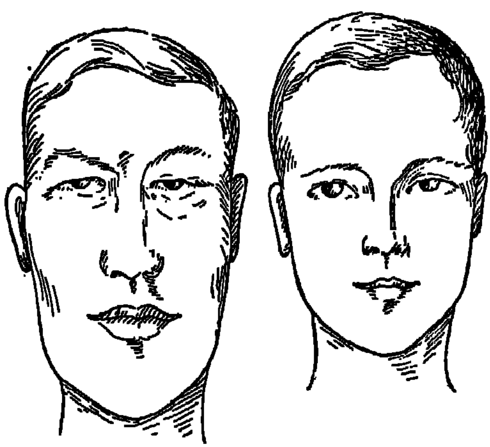


FIG. 42.10. The face of an acromegalic (*left*) and of a normal person (*right*).

not only do the bones of the face and extremities overgrow, but all the bones of the body are urged into an extraordinary overdevelopment. In this way are giants made. Those men of tremendous stature who earn their livelihoods in circus sideshows are victims of overactive pituitary glands. Some of these giants reach the "altitude" of 8 or 9 feet. They would knock their heads against the ceilings in the modern American house, and would need to bend nearly double to pass through a doorway (Fig. 42.13). The tallest which has been reported was a Finn, 9 feet 5 inches. But a Chinese giant has been described who was 8 feet 1 inch, and an American has been recorded who was over 8 feet 2 inches. These are extreme cases, but there are many degrees of *gigantism*, or *giantism*, as the condition is called. A certain French baron some years ago sought by encouraging the intermarriage of giants and giantesses of

type, to produce a race of supermen, but the experiment, for which a million francs were subscribed, proved a dismal failure. The gigantic parents had average-sized offspring. This is a characteristic of pituitary giantism. The giants are usually the children of normal parents, and they themselves have normal children.

Dwarfs.—Deficiency of the growth hormone of the pituitary results in a type of dwarf popularly known as a midget. Midgets are

FIG. 42.11. Skulls of a normal person (*left*) and of an acromegalic (*right*). (*After Cushing.*)

seen most commonly in circus sideshows. They are normally proportioned, of slight build, and usually not unattractive in appearance and personality (Fig. 42.14).

Another type of pituitary dwarf is due to failure of other hormones as well as of the growth principle. The posterior lobe or the hypothalamus (see p. 423) may be involved as well as the anterior lobe. This type of dwarfism is marked by extreme obesity and lack of sexual development. Fat metabolism and carbohydrate metabolism are both disturbed. Juveniles with this type of dwarfism often have voracious appetites and show an inordinate longing for sweets of all kinds, which of course add to their obesity. Not infrequently there are also excessive thirst and increased urine volume (which points to deficiency of the antidiuretic principle of the posterior lobe). Such children are, as a rule, below par mentally,

Fig. 42.12. Photographs of a victim of acromegaly taken at the age of 24 before the onset of the disease, at 29 about the time of the commencement of the disease, at the age of 37, and finally at the age of 42, when the acromegalic changes are pronounced. (*After Cushing.*)

Fig. 42.13. An example of giantism. The boy in the center, 13 years of age, is 7 feet 4 inches tall and weighs 290 pounds. He is seen with his father and brother, who are of normal size.

progress slowly at school, and show an unchildlike lethargy. They are ready to sleep at any time. A subject of this type of pituitary disorder is shown in Figure 42.15. Great obesity without dwarfing may result from a similar disorder in adults. The fat woman of the circus is in most cases an example of this condition.

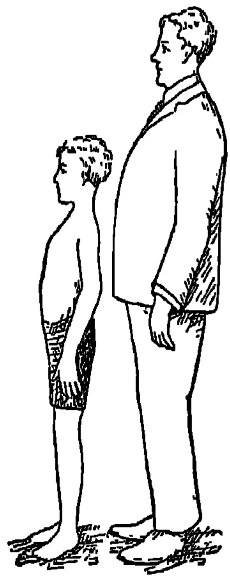


FIG. 42.14. Deficiency of the anterior lobe of the pituitary. The person standing in front is of adult age. The man behind is of average height.

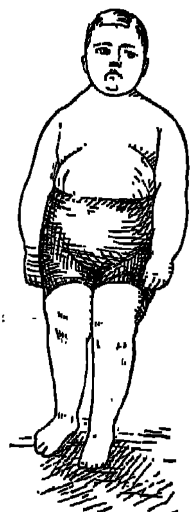


FIG. 42.15. Pituitary deficiency in a child. Hypothalamus is also probably involved. Dwarfing and obesity are the outstanding features.

Diabetes insipidus.—Disease or injury of the posterior lobe of the pituitary or of the hypothalamus (see below) may prevent the production of the antidiuretic hormone. The reabsorption of water from the tubules of the kidney (p. 259) is then greatly reduced with the result that the volume of the urine is increased many fold. This disease is called *diabetes insipidus.*

The Hypothalamus

The hypothalamus consists of several groups of nerve cells situated at the base of the brain near the origin of the stalk of the pituitary. Attention is drawn to this part of the brain here rather than in the section on the nervous system because it is so intimately associated with the functions of the pituitary.

Many nerve fibers arise from cells in the hypothalamus which pass down the stalk of the pituitary to the posterior lobe and control its secretion. Some of these fibers can be traced into the anterior lobe and govern the output of at least some of the hormones produced by this part of the gland. Disease of the hypothalamus causes, therefore, many of the effects which result from disease of the pituitary itself. The hypothalamus contains also nerve cells which regulate the activity of both the sympathetic and parasympathetic divisions of the autonomic nervous system (p. 313).

chapter 43

THE ADRENAL AND PARATHYROID GLANDS

The Adrenal Glands

The adrenal (or *suprarenal*) glands are two bodies shaped something like little cocked hats, and in man are about the size of the last joint of the little finger. They are placed one on each side of the spinal column just above the kidneys (Fig. 43.1). When an

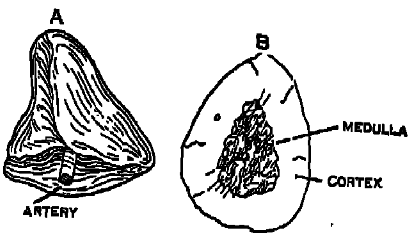


FIG. 43.1. The adrenal gland *A*, external appearance; *B*, sectioned to show the cortex and the medulla.

adrenal is cut through the center, it is found to be composed of two parts—a central dark area and an outer rim of lighter colored material. The central part is called the *medulla*. The outer rim, which reminds one of a skin or rind, is called the *cortex*. The duties of these two parts are entirely different.

The adrenal cortex.—This part of the adrenal gland is absolutely essential to life. An animal lives for only two or three weeks after the cortex of both adrenal glands has been removed. Among its chief functions are the regulation of the water content of the body and the excretion of sodium and potassium. It is also concerned in the metabolism of sugar. When it fails in its functions, as it occasionally does in man, the volume of the blood and other body fluids becomes reduced and the excretion of sodium in the urine

is increased. As a consequence of the latter effect the sodium of the blood and tissues falls to a dangerously low level. The excretion of potassium on the other hand is reduced and its concentration in the blood rises. The sugar of the blood is diminished and its concentration may reach the level at which convulsions occur (p. 237).

Only within recent years has it been known that these important changes in the blood resulted from defective function of the adrenal cortex, but the general symptoms of the disease, which consist mainly of extreme weakness, low blood pressure, anemia, and a peculiar brown pigmentation of the skin, were described nearly 100 years ago by Thomas Addison, a physician of Guy's Hospital, London, England. Failure of the adrenal cortex (adrenal insufficiency) is, therefore, frequently referred to as Addison's disease. An extract of the adrenal cortex, known as *cortin,* is effective in its treatment. A diet with a high content of sodium, but low in potassium, is also of great benefit.

The adrenal medulla.—The medulla of the adrenal gland secretes into the blood stream a hormone which is most commonly known as *adrenaline,* though it also goes by the name of *epinephrine* or *adrenin.*

The actions of adrenaline when injected into the body closely resemble those caused by stimulation of the sympathetic nervous system. This hormone increases the rate and force of the heart beat and constricts the blood vessels, except those of the coronary system and of the muscles, which are dilated; thus the blood pressure is raised. It inhibits the movements of the intestines, dilates the bronchioles, stimulates the smooth muscle in the skin, widens the pupil, and increases the concentration of sugar in the blood. All of these effects can be duplicated by stimulating sympathetic nerves. The function of the secretion of the adrenal medulla in the living animal appears to be defensive or protective in character. It reinforces the action of the sympathetic nervous system in states of emergency or bodily stress, so that the animal is more capable of defending itself against its enemies or of adjusting itself to changes in the environment. Thus, the increase in the sugar of the blood provides an adequate supply of fuel for the contracting muscles. The muscles also fatigue less readily under the influence of adrenaline, and the blood clots more quickly. The latter effect is important in that it lessens the dangers of hemorrhage should the animal

suffer a wound when defending itself or attacking its prey. The dilation of the bronchioles enables a greater volume of air to be breathed and consequently permits the greater quantity of blood

FIG. 43.2. Showing the effect of an extract of the adrenal medulla upon the skin color of the horned toad. *Left,* a normal animal. *Right,* an animal injected with adrenalin; note the pallor. During excitement these animals become pale as a result, apparently, of the passage of adrenal secretion into the blood stream.

flowing through the lungs during the exertion required for fight or flight to be fully oxygenated. The value of the effects upon the circulation—namely, the increased action of the heart, the rise in blood pressure and the dilatation of the coronary vessels—is obvious. Ruffling of the feathers in birds and the bristling of the hairs in fur-bearing mammals are brought about by the contraction of smooth muscle in the skin. These are in many instances defense reactions. As mentioned above, the contraction of the skin muscles

is stimulated by adrenaline. In some cold-blooded animals the hormone of the adrenal medulla has an action opposed to that of the chromatophore-expanding hormone of the pituitary (p. 415). It causes the pigment granules of the chromatophores to gather near the cell centers, thus causing pallor of the skin (Fig. 43.2).

The Parathyroid Glands

The parathyroid glands are four little bodies about the size of peas, lying two on either side of the neck behind the thyroid (Fig.

Fig. 43.3. An animal in convulsions (tetany) as a result of the removal of the parathyroids. Note the stiff positions of the limbs and the bared teeth. (*After Collip, redrawn.*)

41.4). Though so small, they are nevertheless essential to health and, indeed, to life itself. Their name suggests a relationship with the thyroid, but the relationship is purely anatomical. So far as their functions go, they have nothing whatever in common with the thyroid. A close anatomical relationship between two ductless glands having entirely different functions is not unusual; we have seen already other examples of this—the anterior and posterior lobes of the pituitary, and the medulla and cortex of the adrenal.

The story of the parathyroids goes back to the end of the nineteenth century, when they were first discovered and described more as curiosities than anything else. Their important functions were then not even guessed. Their very existence was forgotten soon after their discovery. It was not until two surgeons in Switzerland, famous for their skill in removing goiters, reported that occa-

sionally a patient upon whom they had operated developed convulsions, that attention was again directed toward these glands. With a view to discovering their functions, a French physiologist about this time carried out experiments upon animals. When he removed the parathyroid from rabbits, the animals went into violent convulsions and died. It was immediately realized that the cause of the convulsions in the surgeon's patients had been the unwitting removal of the parathyroids along with the thyroid. The utmost care is now exercised to avoid interfering with these tiny glands when the thyroid is removed by operation.

Tetany.—Tetany is the name given to the type of convulsions which follow the removal of the parathyroids. In human beings the hands and feet are drawn into characteristic attitudes which are readily recognized. In animals the jaws are tightly clamped together, and all the muscles of the body become rigid or show spasmodic contractions; death nearly always occurs (Fig. 43.3). Tetany also occurs in cases of rickets (p. 253), though there is no reason to believe that in this disease the parathyroids are at fault.

The calcium (lime) of the blood always falls to a low level after the removal of the parathyroids, and it is quite evident that the low calcium is the cause of the convulsions. If calcium is injected, so that the concentration of this mineral is raised to and kept at the normal level, tetany is relieved. In 1925 an extract of the parathyroid glands was prepared by Dr. J. B. Collip, of McGill University. This, when injected into the body, raises the calcium of the blood to normal and thus quickly cures tetany. When injected in large amounts into a normal person, it increases the calcium concentration of the blood far above the usual level. From this and other facts it has been concluded that the parathyroid glands manufacture a hormone which alters the quantity of calcium in the body. The greater amount of calcium which is found in the blood after the injection of parathyroid extract evidently comes from the bones, which are largely composed of phosphate and carbonate of lime. After the prolonged treatment of an animal with the extract, the bones become less hard and dense, showing that the minerals have been withdrawn from the skeleton. In man the activity of the parathyroid glands is occasionally exaggerated. The parathyroid hormone is then poured into the blood in excessive amounts and causes very serious effects. The calcium in the blood rises, for, as

has just been said, the hormone dissolves calcium from the bones. These become softer and less rigid, and are therefore likely to be bent into unusual shapes.

Interaction of the Ductless Glands

The glands which have been described have been dealt with as though they were quite independent one of the other. This method of treating them is unavoidable, because this is the way in which they have been studied, and this is the way in which most of the information regarding them has been gained. There is no doubt, however, that their actions are very closely related to one another, and that it is purely artificial to study them separately.

We should look upon the secretions of the ductless glands as forming, with the other constituents of the blood, a suitable environment—an appropriate fluid medium to bathe the cells of the tissues (p. 31). When all secretions are present in their correct proportions, the cells are healthy and they flourish and grow normally. On the other hand, when one secretion in this nicely balanced mixture is present in reduced or excessive proportion, the environment becomes unsuitable, and the cells suffer. Their special functions can no longer be carried out. In order that there may be physiological harmony, each gland must play its part in tune with its fellows.

PRONOUNCING GLOSSARY

Key to the Pronunciations

ā	as in mate	ī	as in pine	ŭ	as in bun
ă	as in mat	ĭ	as in pin	g	as in go
ah	as in father	ō	as in note	j	as in jump
aw	as in fall	ŏ	as in not	k	as in kill
ē	as in seat	oo	as in tool	s	as in seen
ĕ	as in set	ū	as in cure	z	as in zone

′ denotes accented syllable.

Acetylcholine. ă′sĕt-ĭl-kōl′ēn
Achroödextrin. ă-krō′ō-dĕk′strĭn
Acromegaly. ăk-rō-mĕg′ally
Adrenal. ăd-rē′năl
Adrenalin. ăd-rĕn′ăl-ĭn
Afferent. ăff′ĕr-ent
Alveolus. ăl-vē′ō-lŭs
Amino. ăm-ē′nō
Amoeba. ăm-ē′bah
Amylase. ăm-ĭ-lās′
Apnoea. ăp-nē′ah
Arachnoid. ăr-ăk′noyd
Arytenoid. ăr-ĕt-ēn′oid
Autosome. aw′tō-sōm
Axolotl. ăx-ō-lŏt′ĕl

Basilar. băs′ĭ-lahr
Bilirubin. bĭl-ĭ-roo′bĭn
Bronchioles. brŏnk′ē-ōls

Caisson. kā′sŏn
Cathode. kăth′ōd
Cation. kăt′ī-ŏn
Cerebellum. sĕr-ĕ-bĕll′ŭm
Cerebral. sĕr′ĕ-brăl *or* sĕr-ē′brăl
Chorion. kōr′i-ŏn

Chorionic villi. kōr′i-ŏn′ik vĭll-ī′
Choroid. kōr′oid
Chromosome. krō′mō-sōm′
Chyme. kīm
Cochlea. kŏk′lē-ah
Conjunctiva. kŏn-jŭnk-tī′vah
Corpus luteum. kor′pŭs lū-tē′um
Corti. kŏr′tē
Cortin. kŏr′tĭn
Creatinin. krē-ah′tin-ēn
Cretin. krē′tĭn

Decidua. dē-sĭd′ū-ah
Diaphragm. dī′ah-frăm′
Diastole. dī-ăs′tō-lē
Diastolic. dī-ah-stŏ′lĭk
Disaccharides. dī-săk′ahr-īds
Dura mater. dū′rah mā′ter

Efferent. ĕff′ĕr-ent
Endothelial. ĕn-dō-thēl′i-ăl
Enzymes. ĕn′zīms
Epithelial. ĕp-ĭ-thē′lĭ-ăl
Erythrocytes. ĕr-ĭ′thrō-sīts
Eugenics. ū-jĕn′ĭks
Eustachian. ū-stā′ke-ăn

Fauces. faw'sēs
Foetus. fē'tŭs
Fovea centralis. fō'vē-ah sĕn-trā'lis

Gamete. găm'ēt
Ganglion. găng'glē-ŏn
Gene. jēn
Glomerulus. glōm-ĕr'ū-lŭs
Glossopharyngeal. glŏs'ō-făr-ĭn-jē'ăl
Glycogen. glī'kō-jĕn

Haemophilia. hēm-ō-fĭl'ĭ-ah
Haemorrhage. hĕm'ŏ-răj
Hermaphroditism. herm-ăf'rō-dīt-ĭsm

Impulse. ĭm'pŭls

Lachrymal. lăk'rĭ-măl
Leucocytes. loo'kō-sīts

Macula lutea. măk'ū-lah loo'tē-ah
Malleus. măl'ē-us
Meatus. mē-ā'tŭs
Meninges. mĕn-ĭn'jēs
Menopause. mĕn'ō-paws
Monosaccharides. mŏ-nō-săk'ahr-īdes
Morula. mŏr'ū-lah
Mucus. mū'kŭs
Myxedema. mĭks-ĕ-dēm'ă

Niacin. nī'ă-sĭn
Nissle. nĭs'ĕl
Nucleolus. nū-klē'ō-lŭs

Oesophagus. ē-sŏf'a-gŭs
Oosperm. ō'ō'spŭrm
Oviparous. ō-vĭp'ah-rŭs

Pancreozymin. păn-krē-ō-zī'mĭn
Pantothenic. pănt-ō-thĕn'ĭk
Parietal. păr-ī'ĕ-tăl
Parotid. păr-ŏt'ĭd
Parthenogenesis. păr'thĕ-nō-jĕn'ĕ-sĭs
Peripheral. pĕr-ĭf'ĕr-ăl

Phagocytes. făg'ō-sītes
Phrenic. frĕn'ĭk
Pia mater. pī'ah mā'ter
Pituitary. pĭt-ū'ĭt-ăry
Placenta. plă-sĕn'tah
Polymorphonuclears. pŏl'ĭ-mor-fō nū'klē-ars
Polysaccharides. pŏl'ĭ-săk'ahr-īdes
Progestin. prō-jĕst'ĭn
Protein. prō'tēn
Psychic. sī'kĭk
Ptyalin. tī-ă-lĭn
Pyramidal. pĭr-ăm'ĭ-dăl

Scala vestibuli. skā'la vĕs-tĭb'ū-lī
Sclerotic. sklĕ-rŏt'ĭk
Semen. sē'mĕn
Seminiferous. sĕm-ĭn-ĭf'ĕr-us
Spermatocyte. spĕr-măt'ō-sīte
Spermatozoon. sper'măt-ō-zō'ŏn
Stapes. stā'pēs
Steapsin. stē-ăp'sĭn
Stearic. stē-ăr'ĭk
Succus entericus. sŭk'kŭs en-tĕr'-ĭ-kŭs
Sucrase. sū'krāz
Synapse. sĭn-ăps'
Systole. sĭs'tō-lē

Tensor tympani. tĕn'sor tĭm'păn-ē
Thoracic. thor-ăs'ĭk
Thrombocytes. thrŏm'bō-sīts
Trachea. trā'kē-ah
Trypsin. trĭp'sĭn

Umbilicus. ŭm-bĭl'ĭ-kŭs, *or* ŭm-bĭl-ī'kŭs
Urethra. ū-rē'thră

Vagina. vă-jīn'ă
Vagus. vā'gŭs
Vasoconstrictor. văz'ō-kŏn-strĭk'tor
Vasodilator. văz'ō-dī-lā'tor
Vestibular. vĕs-tĭb'ū-lar
Vitamin. vī'tă-mĭn
Viviparous. vī-vĭp'ah-rŭs

Zygote. zī'gōt

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(References include illustrations and footnotes.)